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PRELIMINARY REPORT

PROJECT 1, APPROACH ROADS

1955 GREENLAND PROGRAM

PREPARED BY

ARCTIC CONSTRUCTION AND FROST EFFECTS LABORATORY
NEW ENGLAND DIVISION, CORPS OF ENGINEERS, U. S. ARMY
FOR
WATERWAYS EXPERIMENT STATION
CORPS OF ENGINEERS, U. S. ARMY

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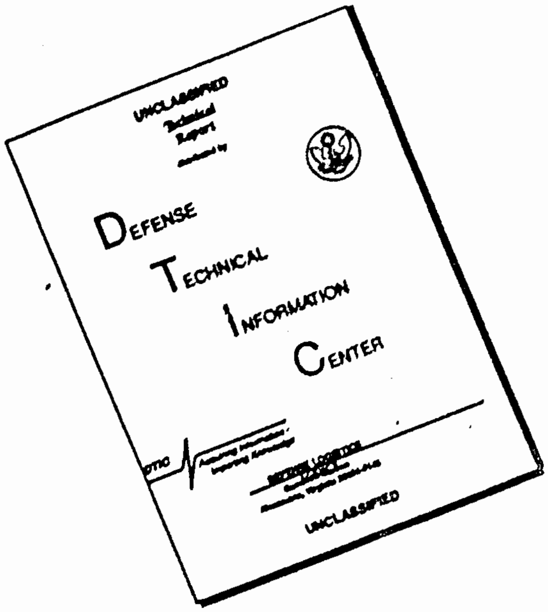

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PREFACE

Primary responsibility for Project 1, Approach Roads, Greenland 1955 Program, was assigned to the Waterways Experiment Station, Corps of Engineers, by the Chief of Engineers, U. S. Army. In a letter dated 18 March 1955, the Waterways Experiment Station requested the Arctic Construction and Frost Effects Laboratory to assume the work of planning and conducting the investigation, including preparation of a report. The Arctic Construction and Frost Effects Laboratory accepted the work in a 1st Indorsement to above letter dated 31 March 1955.

Mr. H. W. Stevens, Head, Greenland Project Section, ACFEL was designated as supervisor for the investigation, organized the project during the planning stages and acted as field advisor during the first part of the field work. Mr. W. C. Sayman and Mr. E. A. Blackey of ACFEL also acted as field advisors during later portions of the field activities. Dr. W. F. Brace was Field Project Engineer and directed all the field activities. The investigation was under the direction of Mr. Kenneth A. Linell, Chief of the Arctic Construction and Frost Effects Laboratory and Mr. James F. Haley, Assistant Chief of the Laboratory, both of whom visited the project in the summer and made suggestions of both short and long range value.

The Waterways Experiment Station reviewed and approved the plan of test and provided support throughout the entire project, furnishing personnel and equipment. WES assigned Mr. J. A. Sutherland as Assistant Project Engineer, Mr. W. C. Hunt as Construction Coordinator, and

Mr. M. D. Beasley as test technician. Mr. Knight and Mr. Rula, Trafficability Branch, WES, worked closely with ACFEL during the planning phase and the start of the field work.

Mr. W. J. Turnbull, Chief, Soils Division, Waterways Experiment Station, and Dr. M. Juul Hvorslev, also from Waterways Experiment Station, inspected the field work in late July and early August respectively. The consulting services of Professor K. B. Woods, Head of School of Engineering, Purdue University, were provided by Waterways Experiment Station in August. Very valuable comments and suggestions were received from all these personnel.

The excellent cooperation received from Lt. Colonel Clarke, Commanding Officer, of the 1st Engineer Arctic Task Force, is greatly appreciated. The skill and effort of the men of The Task Force was basic to the success of the construction phases of the project.

This preliminary report has been prepared by Mr. H. W. Stevens.

TABLE OF CONTENTS

TABLE OF CONTENTS CONTINUED

TABLE OF CONTENTS CONTINUED

TABLE OF CONTENTS CONTINUED

LIST OF TABLES

LIST OF PLATES

PRELIMINARY REPORT
PROJECT 1, APPROACH ROADS
GREENLAND 1955 PROGRAM

PART I - INTRODUCTION

1.01. Purpose. - The project is a continuation of work commenced in Calendar Year 1954. The overall objective is to investigate and develop methods, techniques and design criteria for construction and maintenance of gravel fill roads on ice surfaces, with particular reference to surfaces of the glacier type as exemplified by the TUTO ramp on the Greenland Ice Cap. Detailed Plan of Test for the Calendar Year 1955 program is attached herewith as Appendix A to this report.

1.02. Scope. - This report is preliminary to a final report to be submitted at a later date. The report summarizes the work accomplished and includes some tentative general conclusions. A summary of personnel, materials and equipment used in accomplishing the 1955 program is included (Appendix B is a detailed list of test equipment.). A program for continuing the investigations in 1956 is recommended with data on organization and logistics to aid in planning future work. The program is incorporated in this report as Appendix C.

The purpose of this preliminary report is to provide a basis on which planning for 1956 studies may proceed in advance of analysis of the data accumulated in 1955. Supporting data for the preliminary conclusions given is, therefore, generally not presented.

PART II - ORGANIZATION

2-01. Personnel. - Table 1 of this report shows the organization of the personnel participating in Project 1. The civilian group arrived at TUTO camp 10 June 1955. The military group were assigned to the Project and commenced work on 23 June 1955. The three civilians listed on the organization chart as technical advisors were rotated so that only one was in the field at a time.

2-02. Equipment and Materials.

a. Construction Equipment. - The heavy construction equipment used on Project 1 was furnished from equipment assigned to the 1st Engineer Arctic Task Force, or loaned from the Eastern Ocean District, Corps of Engineers, with a few items loaned by the Transportation Corps. With the exception noted, the following equipment was assigned to the project on 23 June 1955:

1 - 3/4 yd. truck-mounted shovel
* 1 - 3/4 yd. crawler-type shovel
1 - D-8, Bulldozer
2 - 2-1/2 ton Dump Trucks
4 - 10 yd. Mack Trucks
1 - Grader
1 - Jeep
1 - Rock Crusher, 25 yd.
** 1 - D-7 Bulldozer
** 3 - Scrapers
** 2 - Steel-wheel Rollers

* This item received late in season and operated only 2-1/2 days before breakdown.

** This equipment available, but unused because of lack of operators, unusable condition or because equipment was unsuited to job.

b. Construction Materials. - Little to no material was brought in for use in construction. Local borrow materials were used almost exclusively. Four hundred feet of 3 ft. diameter ARMCO culvert were available but because of a change in the Plan of Tests, only 87 feet were used. A very small quantity of lumber was used in connection with culvert construction.

c. Test Equipment. - Approximately 3275 lbs. of equipment was transported by air from ACFEL and WES for use on the project. This equipment may be divided into the following categories:

(1) Soil Testing Equipment
(2) Thermocouples with pipe, thermopanels and housing boxes
(3) Ice drilling equipment
(4) Equipment for experiments with steam-thawing
(5) White paint and spreading equipment for experimentation with white surfaces to prevent thaw
(6) Potentiometer and thermos bottles
(7) Miscellaneous, including cameras, film, reference books, paper, pencils, etc.

A detailed packing list of equipment provided by ACFEL and WES is included as Appendix B to this report.

On 21 June 1955, fire destroyed the Soils Laboratory hut including 99% of the soils testing equipment furnished by WES. Although WES promptly proceeded with replacement of the items, a period of 2-1/2 weeks ensued, during which time no soils testing equipment was available except what could be salvaged or that others (specifically Mr. Arthur of SIPRE Project 18B) could loan.

Some equipment was supplied by the 1st Engineer Arctic Task Force and included:

1 - Transit
1 - Level
1 - Level Rod
1 - Stadia Rod
1 - 100 ft. Steel tape

On several occasions, a theodolite was borrowed from Mr. Spencer Taylor, SIPRE Project 18A, for use in connection with movement surveys.

2-03. Work Output of Construction Equipment. - Table 2 lists the work accomplished in the time available, and with the equipment as listed in Section 2-02a. A breakdown of in-place yardage versus time is provided, together with the percentage of deadline time and standby time.

It should be noted that the efficiency of the construction equipment was reduced because of the unusually rough and heavy material which it was called upon to move; the light 3/4 yd. shovel, for example, was inadequate in the boulder borrow, as well as too small to service the 10 cu. yd. trucks. Stockpiling material from the surface 18" to 30" of soil required an unusual bulldozer/shovel ratio. All the equipment except the Mack trucks was in poor repair and well worn when assigned to the project. Constant repair work was necessary, which was hampered by a shortage of spare parts. One Mack truck was deadlined until 1 August for lack of tires. The result was an inordinate amount of dead line time. Other conditions which affected the progress made by the equipment included the length of haul, which increased as the road lengthened, the rather steep slope which the trucks had to ascend to reach the end of the road, and the efficiency of the operators who required some time to become proficient in handling the equipment in the unusual terrain and in the rough bouldery material.

PART III - ENVIRONMENTAL CONDITIONS

3-01. Weather. - At the TUTO camp, a station for obtaining meteorological data was maintained with readings taken at 8-hour intervals. Air temperatures, relative humidity, cloud cover, wind speed and direction and barometric pressures were recorded. Hygrothermographs recording air temperatures and relative humidity were installed and maintained at a station on the Ice Cap at approximately one mile inland and at a station at the intersection of the TUTO approach road with the "P" Mtn. road. The complete record of meteorological data accumulated will be included in the final report, but in this preliminary report only a brief summary of the general characteristics will be presented.

The most important characteristic of the weather, as it affected the Project during the summer of 1955, was the shift in time of occurrence of the warm season over that of the summer of 1954. This year, degree-days of thaw, based on air temperatures, started to accumulate by the first week in June and by the 22nd of June, which was the start of above freezing air temperatures in 1954, over 70 degree-days of thaw had accumulated. However, in 1955, thaw practically ceased by the middle of August, whereas in 1954, high thawing temperatures persisted until the last week in August. Thus, the thawing season occurred several weeks earlier in 1955 then in 1954, and the greatest concentrated thaw was in late June and first of July, rather than in late July and first of August as in 1954. The total accumulated degree-days of thaw in 1955 were considerably less than in 1954.

While air temperatures are used as a basis for the foregoing summary of the seasonal thaw conditions, solar radiation is at least as important as air temperature in the effect upon surface thawing. However, in this case, it is probable that the intensity of solar radiation generally followed a pattern similar to the air temperature. The meteorological records show that, in 1955, there was a considerably higher percentage of clear days during June and the first of July than in late July and the month of August when storms and whiteouts were prevalent. In 1954, clear days were more prevalent in late July and August than in June.

Other meteorological characteristics remained similar to 1954 except that difficulty with storms, high wind and snow occurred in late August this year rather than in early June as was the case in 1954. Severe storms (resulting in one case, in a loss of two working days) occurred the last week of July and first week of August 1955. During the same period in 1954, a few minor storms occurred but only one day of work was lost.

3-02, Surface Conditions. - The change in the time of thaw described in paragraph 3-01 effected the surface conditions which prevailed during the working season, and consequently upset the planned schedule of investigations and the construction program. Based on 1954 surface conditions, it was planned that construction of gravel roads could not be commenced until the last week in June because the frozen ground surface would prevent borrow operations. Actually thaw penetration was 10 to 12

inches by 10 June 1955 and much work could have been accomplished in the month of June. Plans and preparation for such an early start of operations not having been made, advantage could not be taken of this unexpected condition. Storms, snow and freeze-up resulted in stopping work earlier in August than was the case in 1954, the overall result being a shorter actual working time than had been planned. The early thawing of the ground surface also prevented study of thaw phenomena in the early stages, a study which was considered quite important.

The early warm season was reflected in the development of melt water flow and the snow melt on the ramp surface. The greatest activity of melting snow and melt water flow occurred in late June and the first weeks of July. The subsequent early reduction of run-off, in mid-August, shortened the period during which observations could be made of the effectiveness of test sections and culvert installations erected to investigate methods of controlling melt water flow.

PART IV - SUMMARY OF 1955 INVESTIGATIONS

4-01. General. - The investigations as actually conducted, followed closely the Plan of Tests (See Appendix A) as revised in the early part of the field season. As soon as possible after the start of field operations, a reestimate of feasible investigations was made in the light of available equipment, weather and surface conditions.

4-02. Road Construction.

a. Reconstruction of 1954 Road. - Observation of the road leading up the ice ramp and constructed in 1954 showed that, after thawing, the gravel fill contained soft spots. Traffic over these portions of the road increased the softening and, as thaw progressed and traffic increased, large sections of the upper portion of road became impassable for even light vehicles. Investigation showed that the type of material used was largely responsible for the condition. Repair of the road was not considered feasible. However, the section of road could not be abandoned because the Plan of Tests included the extension of the road to higher elevations. Accordingly, the first construction undertaken was the rebuilding of sections of road. The existing fill was bulldozed out and replaced with two feet of boulder fill with 6 inches of random gravel surface or a total fill of 2-1/2 ft. A total of 1600 ft. of road was so reconstructed from Station 31+00 to Station 47+00 (Plate 1). During this reconstruction, the investigational purposes of the project were advanced by the use of various types of surfacing material and by construction of a section of road from about Station 33+00 to Station 34+00 with an 18"

to 20" fill of crushed rock. The material pushed out from the old road was used to construct blankets or berms beside the road to protect the adjoining ice surface from excessive melting. Some of the material was used to construct diversion dikes or wings for control of melt water flow adjacent to the road. As a result of the failure of sections of road constructed in 1954, it is concluded that the material used as principal fill for the road must be highly permeable and that the silty gravelly sand available as surface borrow in the TUTO area is unsuitable for this purpose.

b. Transverse Road. - In accordance with the Plan of Tests, a section of transverse road (so-called because the alignment was transverse to the direction of melt-water flow) was constructed. As shown on Plate 1, the road was built commencing at Station 27+16.5 on the main road and in the direction of the base of the moraine formation north of the ramp road. This alignment was chosen because it was originally considered the road might be used for access to the site of the ice tunneling project located in the ice cliff at the base of the moraine. An early survey of the proposed road showed that the quantities of borrow required and the bridge and culvert construction necessary were so great as to require more time, equipment and man power than could be allotted to that phase of the project. Moreover, the investigational requirements of the Plan of Tests could be satisfied by the construction of a much shorter road. As shown on Plate 1, a section of road approximately 800 feet long was built. The cross section design was similar

to that found most effective in reconstructing the main road except that a deeper fill was used, to allow the installation of cross drainage culverts. A 2-1/2 foot minimum boulder fill base was used with 6-inch surface of random fine gravel. To conserve time of construction, the roadway was reduced in width from 30 feet used on the main road to 24 feet, with approximately 1 on 1 slopes. Four culverts were installed at places where major melt water channels crossed the road alignment. Each culvert was of a different type, in order to compare the effectiveness of the several possible designs.

A 1 on 4 slope was constructed on the down slope side of one section of the transverse road to investigate the advantage of such procedure in protecting the adjacent ice surface from excessive melting during the summer with consequent sloughing and sliding of the road shoulders. As a result of observation of the functioning of the culverts, it was decided that the entrance and exits of the culverts would need protection from undercutting by the melt water flow. Two culverts were, therefore, provided with gravel berms, with the other two culverts left unprotected to provide a basis for comparison.

On the basis of observations during the short season of melting which remained after construction of the transverse road, it is concluded that it is feasible to construct gravel fill roads transverse to the direction of flow. Additional observations of the performance of the road are needed to determine the extent of maintenance and protection required against the eroding effects of several seasons of melt water flow.

c. Main Road. - The main road was extended from Station 47+00 (end of road in 1954) to Station 98+00. The basic cross section was fixed as a 30-ft. wide roadway with 1 on 1 slopes, made up of 2 ft. of boulder fill and 6 inches of random fine-grained gravel surfacing, with a 6 to 8 inch crown. However, at various locations along the road, test sections were constructed to investigate the effectiveness of various depths of fill and combinations of materials. From Station 47+00 to 50+50, 6 inches of crushed rock was used for surfacing over the 2 foot boulder fill in place of the usual 6 inches of random fine gravel. From Station 58+00 to Station 59+00, 18 to 24 inches of random fine gravel was placed on 12 inches of boulder fill. Between Station 59+00 and Station 60+00, one foot of crushed rock only was used. Station 60+00 to Station 63+00 received one foot of boulder fill surfaced with one foot of random fine gravel fill.

Between Station 76+00 and Station 79+00, a test lane, designated as Test Lane #5, was constructed similar to Test Lane #3 built in 1954 between Station 10+00 and Station 14+00, (See Plate 1). Three 100-ft. sections were built having 2-ft., 3-ft., and 4-ft. depths of boulder fill, respectively, each section being surfaced with 4 inches to 6 inches of crushed rock. The test lane was provided with thermocouple installations to allow the measurement of temperatures in the fill and in the ice to a depth of 15 ft., at the center of each section. Additional thermocouple installations were made at the toe of the slope on each side of the center section, and at a point 60 ft. from center line of road. Vertical spacing of thermocouples was 12 inches. A reference

plate was placed on the ice surface beneath the center of each section with a plastic tube leading to the road surface, to permit periodic reading of elevations on the ice surface beneath the fill.

The new road constructed in 1955 made use of a highly permeable fill (boulders or crushed rock) throughout the entire length and consequently remained stable and trafficable for the remainder of the work season. The various test sections interspersed along the road likewise remained stable, including the section having only one foot of crushed rock. However, these observations are not conclusive inasumch as the road has not yet been subjected to the height of the melt season.

d. Evaluation of Roads. - Observations and measurements of the performance and capacity of the existing roads were made throughout the field season.

With the exception of the last 1600 feet of the road on ice, the roads constructed on the ground and on the ice in 1954 were in good condition at the start of the 1955 season and reamined satisfactory through the work period. All roads were subjected to heavy traffic from the construction equipment and from the operations of the Transportation Corps in freighting supplies and equipment to the sled trains. As described in Section 4-02a., 1600 feet of the ramp road on the ice required rebuilding when it became impassible to traffic. This section of road was originally constructed with a smaller depth of fill and with a finer grained material than the remainder. A few soft spots developed in other sections of the road on the ice although not critical enough to require rebuilding.

At representative locations on the roads, on the ground and on the ice, California Bearing Ratio tests were conducted on the surface and at several depths to 18 inches. Water content and density were measured with the CBR tests. Representative samples were bagged and shipped to the New England Division Laboratory for classification and testing. Special study was made of the characteristics of the soil in the soft spots in the road, to aid in determining the cause.

4-03. Construction of Loading Platforms. - The 1st Engineer Arctic Task Force was assigned responsibility for the construction of a loading platform at the end of the road constructed in 1954. This project was Project 2 of the 1955 Greenland Program. It became apparent in the early stages of the field season, that inasmuch as the same equipment and men were to be used for Project 2 as for Project 1, it would be more efficient for the work to be carried on concurrently with Project 1. Work was commenced following plans furnished by the 1st Engineer Arctic Task Force. The platforms were to be constructed of gravel fill retained by a bulkhead and were to consist of one 20 ft. by 75 ft. strip attached to the south shoulder of the road and one platform 75 ft. square off the road, 25 feet from the first platform. It was decided to locate the platforms between Stations 46+25 and 47+00 of the main road. The bulkheads were constructed by setting posts approximately 4 inches by 5 inches and 7 ft. long in holes drilled in the ice with a 6-inch diameter power auger. Posts were set about 5 feet deep. Sections of metal pierced plank were nailed to the posts to complete the bulkhead.

The strip adjacent to the road was backfilled with gravel when the road was rebuilt at that location. The separate platform was never filled with gravel because the extension of the main road reduced the need for the platform and because it was found that the melting of the ice surface around the bulkheads was so great that the posts were no longer secure, and some of them broke off from the pressure of the gravel fill. The gravel tended to spill out from under the pierced planking as the opening between it and the ice surface became larger. Melt water flow undercut and saturated the gravel. When the need for the loading platform was found no longer pressing, further construction on this platform was abandoned, in accordance with a decision of the 1st Engineer Arctic Task Force.

At Station 97+00, the end of the road as extended in the 1955 season, a gravel pad was constructed for use as a loading platform. A section 75 ft. square was built, centered on the end of the road, with a 2 ft. depth of well-compacted boulder fill. No bulkheads to retain the fill were used, but since the shoulders of the compacted boulder fill stood with fairly steep slopes, it was considered that this pad would be satisfactory for loading from trucks or lowboys directly to sleds.

4-04. Control of Melt Water Flow. - During the summer thawing season, the ice surface upon which the gravel roads were to be constructed becomes eroded and channeled by runoff from melting snow and ice. The control of this flow is necessary to maintain the stability of the roads. Experiments to develop methods and techniques for such control were conducted as an important phase of Project 1.

a. Culverts. - Except for the exceptionally favorable condition of a road which remains at all times on a drainage divide, any road constructed within the marginal area of the Greenland Ice Cap must be expected to have to cross one or more of the melt water channels which become eroded in the ice surface and which frequently contain fairly large flows of water. As a start toward developing methods of coping with this situation, experimental types of culverts were installed in the transverse road as follows:

(1) 36-inch diameter, Armco, round, metal culvert laid directly on the ice and secured in place with hand-placed boulders.

(2) 30-inch diameter, 55-gallon drums with ends removed, welded together. The drums were bedded on 4 inches to 6 inches of hand-placed boulders.

(3) A french drain type, constructed by hand placing boulders in a trench approximately 2-1/2-feet wide.

(4) A bridge-type culvert consisting of half a 36-inch diameter, Armco, metal culvert set on plank footings, spanning the melt water channel in the ice.

Some measurements of quantity and velocity of flow through the culverts were made and observations of culvert performance were recorded through the rather short part of the thaw season which remained after their completion. Conclusive statements as to performance will not be possible until observations have been made through a complete thaw season. However, it was observed that the Armco, 55-gallon drum and french drain types of

culvert became perched above the adjoining ice surface as the flow of melt water and surface thawing lowered the level of the ice. By the close of the season, no water was flowing through these culverts. It is possible they will not function next season, but it is also possible they will serve a useful purpose in controlling the early runoff from melting deep snow. The flow through the bridge-type culvert continued throughout the season, as the flowing water cut its own channel in the ice surface and, therefore, in the one season, this type of culvert appeared to be the most feasible. However, there is a possibility that the flowing water will eventually undercut the footings supporting the half Armco culvert.

b. Channel Diversion. - A somewhat different problem in the construction of roads in the marginal area of the Ice Cap is the diversion of flow away from the road alignment, first to provide a "dry" ice surface upon which to build the road (that is, one which is essentially free of flowing water) and second, to prevent washing away, undercutting, or saturation of the fill after construction.

An effective technique used in the 1954 construction was again employed in 1955. It has been found that the melt water channels can be induced to form in positions where they will not affect the embankment. A trench is plowed in the desired location while there is still substantial depth of snow on the surface and before melt water channels have become strongly developed. At the lowest elevations this must be fairly early in

the season, but at the higher elevations this procedure is effective through the summer. Once the trench is formed, as by a bulldozer, it is only necessary to divert into this shallow trench any streams of flowing water which it is desired to control, after which the flow tends to develop a shallow channel in the ice. The flow then will remain in the channel at least the remainder of that thawing season.

It was also found possible for a small group of men to divert streams, or control their direction, by simply chopping short connecting channels or by deepening existing channels at the proper locations with axes, ice chisels, etc. (where multiple channels exist). A surprising degree of control could be obtained in this manner, especially in diverting the larger streams from the toe of fill or into culvert entrances.

A most effective procedure for diverting flow channels from the toe of fill, which could be used at any stage of thaw, was by the construction of gravel dikes or wings projecting approximately 50 feet from the shoulder of the road and alignment sufficiently down slope for positive outward drainage. These dikes collected the many small streams which tended to flow towards the road and diverted them far enough away from the road so that they had no detrimental effect. A number of these dikes were constructed in 1955 at appropriate places along both the 1954 section of road and the newly constructed 1955 road. As soon as the dikes were placed, thaw of the underlying ice was virtually halted, while the adjacent ice continued to melt at a rapid rate. Consequently, melt water flowing along the uphill slopes of these dikes was in a week or two actually running in contact with an ice prism forming the base of the dike,

and the earth portion was elevated in a relatively high and dry position. While the ultimate effectiveness of the dikes cannot be conclusively determined by the observations to date, which have covered only a small part of a single thaw season, it is tentatively concluded that the construction of such dikes should be standard procedure when building gravel roads parallel to the line of melt water flow, in zones subject to heavy run-off.

4-05. Investigation and Control of Ice Surface Melt. - It was observed at the close of the 1954 investigations that the ice surface adjacent to the gravel road melted to such an extent that the road became perched on an ice ridge with some danger to its ultimate stability because of sloughing off of the shoulders. In 1955, this effect became even more pronounced, to the extent that it was concluded that the control of the melting ice surface was vital to the maintenance of the road, if it was desired to preserve it for more than one or two years. The Plan of Tests for 1955 called for investigating methods of coping with this problem. Therefore a number of test sections were constructed and studies and measurements were made to investigate (a) the extent and rate of actual ice melting, (b) factors influencing rate of melting, and (c) methods of control.

a. Routine Melt Observations. - In order to measure the rate and extent of melting of the ice surface under and adjacent to the road, a program of routine measurements was carried out during the field season.

Cross sections were taken periodically of representative sections of the road and ice surface. Sections were taken at the start, middle and close of the season except in cases where the road was newly constructed and time did not allow more than two sets of sections.

A reference plate was placed in the center of each section of Test Lane 3 when it was constructed in 1954. An aluminum plate was placed on the ice surface with a capped plastic tube leading from the plate to the surface of the road fill. A steel rod may be inserted in the plastic tube until it touches the aluminum plate. Levels may then be taken on the end of the rod and the amount of ice thawing beneath the fill determined. Levels were taken periodically on these plates during the 1955 season.

Similar plates were installed in Test Lane 5 constructed in 1955. However, this test lane was constructed so late in the season that only levels for reference in future years could be taken.

b. Effect of Shoulder Treatment. - From observations made in the 1954 investigations, it was considered that the ice surface adjacent to the road might be protected by the construction of thin berms or blankets of gravel extending outward from the toe of road for distances of perhaps 25 to 50 feet. To determine the most effective design for such berms, a number of test strips were constructed at various representative locations and of various types and methods of construction. A list and a brief description of these test sections follows:

(1) Sta. 22+00 to 22+50, south side of main road, gravel berm, 1 ft. deep, 25 ft. wide.

(2) Sta. 22+50 to 23+00, south side of main road, gravel berm, 1 ft. deep, 25 ft. wide. Painted white 7 July 1955. Painted surface subsequently destroyed by wash of melt water and displacement of gravel surface.

(3) Sta. 23+00 to 23+50, south side of main road. Gravel berm, 1 ft. deep, 25 ft. wide.

(4) Sta. 23+50 to Sta. 24+00, south side main road, 4:1 gravel slope.

(5) Sta. 53+50 to Sta. 54+00, both sides main road, 4:1 gravel slope.

(6) Sta. 54+00 to Sta. 55+00, both sides main road, 12-inch gravel berm, 40 ft. wide.

(7) Sta. 62+70 to 63+00, north side main road, 3 inches crushed rock berm, 20 ft. wide, painted white.

(8) Sta. 63+00 to 63+40, north side main road, 6 inches crushed rock berm, 20 ft. wide.

(9) Sta. 63+40 to 63+60, north side main road, 6 inches crushed rock berm, 20 ft. wide painted white.

(10) Sta. 4+20 to 5+00, west side transverse road, 4:1 gravel slope.

At each of these test sections, reference points were marked so that measurements could be made of the changes in elevation of the berm surface and the ice surface. Cross sections were obtained at time of installation and at least once more depending upon the time remaining after construction. Visual observations were also made of their performance for the remainder of the thaw season after their installation.

c. Effect of Dust and Soil Fines on the Ice Surface. - It was observed that the melting of the ice surface adjacent to the road was more intense than at a considerable distance from the road, due to the dust and other soil fines which were spread over the surface. Cross sections of the road were extended to 500 feet on each side at three representative locations, to determine the variation in amount of melt with distance from the road. Measurements were made of the dust concentration at various distances from the road, on these cross sections, and samples were obtained for testing in the laboratory for grain size and composition, and for experiments to determine the effect of surface concentration of soil fines on rate of melting when subjected to heating by radiation.

4-03 ~~4.d.~~ Inspection of NUNA Road. - Helicopter inspection of the Nuna Road (See Figure 7) was made by Mr. Linell on 11 August. The entire length of the road was flown twice at low altitude, and a number of stops were made for photographs and surface inspection. The road appeared in reasonably good shape except where it crossed the wet bottoms of drainage valleys (See Figure 7) and at a few other points where seepage was emerging. Soft, wet spots with settlement were found where cuts had been made on north slopes. Permafrost is evidently much closer to surface on north slopes.

It was concluded that the same criteria applicable for construction in the TUTO area also apply for the NUNA Road area. Roads should be built entirely as fills, if possible, and cuts should be avoided, particularly on northerly slopes.

4-C7. Thaw Penetration and Soil Temperature Studies. - The design of roads or other facilities on permafrost involves the determination of depth of freezing or thawing which will occur in the work area. Design of gravel roads on ice is a closely similar problem. Therefore an important phase of Project 1 was the collection of data on the depth and rate of freeze and thaw. In addition to aiding in the immediate investigation, the data accumulated will be of long range value in the continuing search for better design methods and procedures.

a. Thaw Penetration Measurements. - Continuing and augmenting measurements made during the 1954 investigations, the depth of thaw was measured by test pitting at least twice a week at seven locations representing different types of ground surface conditions. Three of the test pit sites were the same as used in 1954, for comparison of the two seasons. In addition to the measurements of thaw penetration in the natural surface, measurements were obtained in the gravel road fills by means of the thermocouples installed in 1954, augmented by occasional direct measurement by test pit. Soil characteristics measured in conjunction with the recording of thaw penetration included water content (determined periodically to record the change with time), density and gradation.

Thaw penetration for the season varied between 20 inches in an area (Test Pit No. 5), which had been stripped for borrow in 1954, to 39 inches in an undisturbed, dry polygon area (Test Pit No. 7). Thaw penetration progressed rapidly until approximately 10 July when penetration slowed and in some cases ceased entirely. By 20 August, the surface had, in many places, started to refreeze and freezing in some pits had occurred from the bottom up.

b. <u>Thermocouple Installations.</u> - Three test lanes were instrumented with thermocouples during the 1954 investigation, shown on Plate 1 as Test Lanes 1, 3 and 4.

In Test Lane 1, thermocouples were installed at three sections having 2 ft., 3 ft., and 4 ft. depths of fill respectively. Thermocouples were installed at the center of the fill in each section and were extended five feet into the subgrade. Thermocouple strings were also installed to 5 foot depths at the toe of fill on each side of the 3 foot fill section and at a point about 80 feet from the road in the undisturbed ground.

In Test Lane 3, thermocouples were installed in the gravel fill and ice subgrade in the center of each of the 4 sections of the lane (2 ft., 3 ft., 4 ft., and 5 ft. depths of fill). The thermocouples extended 15 feet into the ice under the 2 ft., 3 ft., and 4 ft. fill sections and to 30 feet under the 5 ft. fill section. An installation was made to a depth of 15 feet at the toe of fill on both sides of the center of the 5 ft. fill section and on the same cross sectional line an installation 30 feet deep was placed 70 feet off the shoulder of the road in the undisturbed ice.

Test Lane 4, also constructed in 1954, consisted of a deep fill (approximately 10 ft.) on the ground. One thermocouple string was installed in the center of the lane extending two feet into the subgrade.

Test Lane 5 was constructed in 1955 and contains three sections of 2 ft., 3 ft., and 4 ft. depths of fill. Thermocouples were installed in a pattern similar to Test Lane 1 with an installation in the center of

each section end, at the 3 ft. fill section, one at the toe of fill on each side of the section and one offset about 50 feet from the centerline of road.

Temperatures were read on all thermocouples installed in 1954, on 31 March, 26 April, and 3, 11, and 18 May 1955. Commencing on 16 June 1955, when the Project 1 personnel took over the readings from the Eastern Ocean District Personnel, readings were obtained every three or four days until 20 August. Arrangements were made with the 1st Engineer Arctic Task Force to continue readings once a week until 1 November 1955. Additional readings will be taken during the winter when feasible. Commencing 1 March 1956, readings will be taken every two weeks until other arrangements are made.

The thermocouples in Test Lane 5 were not installed until the middle of August 1955, so that readings from this group commenced 17 August 1955.

In general, the thermocouple installations were found to be in excellent condition after a year of operation. The installation in offset from Test Lane 3 required replacement. The melting of the ice surface during the two summers exposed about 7 feet of the thermocouple string, and during the winter a fox chewed the plastic tubing encasing the thermocouple wire, breaking several wires. Considerable time was also spent in relocating the top thermocouple in each of the installations in the gravel fill of the roads, as additional filling or grading of the surface had changed the depth at which they had originally been set.

Thermocouple readings in Test Lane 1 (on ground) showed that thaw penetration was 30 to 32 inches in the center of the road regardless of depth of fill. Thus, in the 2 ft. fill section, thaw penetrated approximately 8 inches in the original subgrade but in the 3 ft. and 4 ft. fill sections, thaw never reached the original subgrade. In Test Lane 4 (deep fill on the ground) thaw penetrated over 8 feet in the dry, coarse, bouldery fill but left approximately 2 feet of fill still frozen. In Test Lane 3 (on the ice), thaw penetration varied with the depth of fill from approximately 3-1/2 feet in the 5-1/2 foot fill section to approximately 2.3 feet in the 2-1/2 ft. fill section. Thus, approximately 2 feet of fill remained frozen in the 5-1/2 ft. fill section and only approximately 0.2 ft. in the 2-1/2 ft. fill section.

c. Measurement of Air-Surface Heat Exchange. - Commonly used methods for predicting depths of thaw and freeze in the ground use air temperatures as the basis for computation. However, air temperatures measured above the surface (for example, at a height of 4-1/2 feet), differ substantially from temperatures, particularly in areas such as TUTO, where the relative effect of solar radiation is known to be extremely large. While empirically-obtained correction factors have been used to take this difference into account, this approach is subject to serious inaccuracies.

As a preliminary step toward more exhaustive investigation of this problem, special measurements were made of air temperatures and related meteorological characteristics in the zone of air immediately above

the surface of the gravel roads and of temperatures in the top 3 feet of the roadway. Two locations were instrumented; one in the 3 ft. fill section of Test Lane 1 and one in the 5 ft. fill section of Test Lane 3. In each case the installation was placed approximately 3 feet in from the edge of road shoulder. Thermocouples in radiation shields were fixed at 6 in., 18 in., and 54 in., above the surface. Directly under these thermocouples, thermocouples were set at the surface and at depths of 1/4 in., 3/4 in., 2-1/2 in., 6 in., 1 ft., 2 ft., and 3 ft. Temperatures at greater depths were available from the regular thermocouple installations in the center of the test section. One complete set of readings was taken at each installation at least every two days with a few periods when readings were taken every two hours for the greater part of a day. Readings at Test Lane 3 were made between 7 and 9 A.M. and at Test Lane 1 between 9 and 11 A.M. With the temperatures, the velocity and direction of wind were measured at several levels with a hand held anemometer. Humidity was measured with a psychrometer and the cloud cover and time of day were recorded. From time to time, changes were made in the installations and in procedures as experience showed methods of improving the original plans. Analysis of the results has not been made as yet. The results are expected to be of substantial help in planning a comprehensive study for 1956.

4-C8. Measurements of Effect of Ice Movement. - In 1954, in a SIPRE project, measurements were made of the movement of the ice on the TUTO ramp. It was reported from this study that for approximately the

first 3000 feet from the edge of the glacier, the surface of the ice was practically stagnant. The section of ice beyond the first 3000 feet moved relatively fast; as much as 5 ft. in the summer season. The intersection of these two sections is readily apparent on the ice surface in the form of a zone of hummocks and shear plane lines. It was anticipated that this ice movement might have some effect on the road. However, no effects were observed at the start of the 1955 season on the section of road constructed in 1954. Although time, equipment, and personnel were limited for work on this phase, some measurements were made in 1955 of the movement of the road for comparison with movement of the ice. Ten steel pins were placed in the road fill. The pins were approximately 18 inches long and were set with their tops 6 inches below the road surface to prevent disturbance by traffic. Pins were set at points along the main road below the hummock area and through the hummock area with one pin set at Station 6+50 of the transverse road. The main road pins were set 5 July and the pin in the transverse road 27 July. The locations of the pins were determined precisely by triangulation from stations on the ground using a theodolite. The base line stations were the same as used in 1954 for the ice movement survey. The locations of the pins were redetermined by theodolite approximately 1 August and again just prior to the end of the field season. The distance between pins was carefully taped at time of each triangulation survey.

Computations of the movements are not yet complete, but tentative sample results are listed as follows:

Period 5 July through 3 August

	X	Y
Point 1	0.33 ft.	0.71 ft.
Point 2	0.27 ft.	0.55 ft.
Point 4	0.27 ft.	1.60 ft.
Point 20	0.19 ft.	0.63 ft.

Points 1, 2 and 20 are below the hummocky zone and Point 4 is in that zone. The movement is predominantly toward the glacier edge and slightly southward. It is significant that differential movement exists as this should tend to shorten sections of the road or change the alignment. However, no effect on the road surface was detected during the 1955 season.

4.09. Survey of Borrow Materials. - A survey of borrow materials in the immediate area of the TUTO ramp was made in anticipation of additional work in the area in future years. The survey may also provide valuable information on methods of locating borrow in other areas where the terrain is similar. The relation of the location of suitable borrow materials to terrain characteristics was studied, with the object of improving methods of using aerial photographs to locate likely sources of borrow materials.

PART V - CONCLUSIONS FROM 1955 STUDIES*

5-01. The conclusions presented herein are tentative, based on observations made in the field with only such study of data as could be accomplished during the field season.

a. It is feasible to construct and maintain emergency military gravel roads on ice in the marginal area of the Greenland Ice Cap.** The life expectancy which can be developed in such roads without necessity for reconstruction is not yet determined.

b. Extension of the road to higher elevations on the Ice Cap slope is very important, since the feasibility of earth fill construction on the Ice Cap should not be judged solely by its performance at the lowest elevation, adjacent to TUTO. The optimum elevation for earth fill construction would appear to be at or near the firn line.

c. Dust is the major adverse factor in construction of roads on ice because of its effect in causing accelerated thawing of the surface, parallel to the road. Successful control of dust would substantially increase the effectiveness of this type of construction.

d. The nature of the borrow materials available and required for road construction on ice are such that the construction equipment must be exceptionally heavy and in good repair to be efficient.

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* In general, conclusions given in the present report are limited to those which may be reasonably accepted for planning purposes without supporting data.

** It is considered that this conclusion would also apply to air strips constructed at locations having sufficiently level terrain.

e. Inasmuch as the thaw season commenced earlier and ended earlier in 1955 than in 1954, requiring revision of the planned schedule of investigations, it is concluded that an extremely flexible program is necessary to take full advantage of the working season, whenever it may occur.

f. Observations to date indicate that a highly pervious material should be used for the roads on ice. In the TUTO area such a material is available as random borrow consisting principally of boulders and cobbles. Thickness of road fill has been governed by the size of the boulders available and by considerations of snow depth and drifting. A thickness of two feet has been found to fulfill all requirements but less thickness may be found feasible when the results of observations on test sections constructed in 1955 are available. A thin layer of selected surfacing material (not over 6 inches) over the coarser underlying fill has been found desirable for a smooth riding surface and to allow fine grading to provide a crown. However, material high in clay, silt or fine sand sizes is undesirable because of the dust problem which results and because of the possibility of reducing permeability of the underlying free-draining material. Crushed rock appears to be the most desirable material for surfacing but experiments to evaluate the feasibility of using the more easily obtained random silty, gravelly sand are not yet complete.

g. Adjacent to the final 3000 feet of road, the melting of the ice surface has been so great that the road is perched high on an ice

ridge and it is doubtful if the edges will remain stable through one more thaw season unless measures are taken to prevent additional melting at the shoulders.

h. Berms are effective in preventing excessive melting of the ice surface adjacent to the road. The most efficient design will be determined after effect of the test berms constructed in 1955 have been observed through the 1956 season.

i. It is feasible to construct a gravel road transverse to the direction of melt water flow and to maintain it in a stable condition through at least one thaw season.

j. Observations over a brief thaw period, of the performance of the four types of culverts installed, indicate that an arched or bridge type of culvert is most efficient, at least for one season.

k. Melt water channels may be induced to form in predetermined positions or existing flow may be directed as desired, (1) by plowing trenches in the snow, (2) by chopping new channels with axes and ice chisels, (3) by deepening existing channels selectively at proper locations, or (4) by the construction of earth training dikes.

l. Suitable borrow materials for a considerable amount of road construction on the ice are available, but the haul distance will become increasingly longer, as the borrow immediately adjacent to the entrance of the road onto the ice is nearly exhausted.

m. In anticipation of the possibility that ramps may be required elsewhere in Greenland, where thaw may be heavier and/or the surface

rougher, or that construction may be necessary during periods of the year when potential borrow is solidly frozen, consideration should be given to the following possibilities for situations where emergency military construction may be necessary:

(1) Pile-Supported Road Structure. - This could be a simple bridge for crossing a stream or a trestle of some length. The shading effect of the floor structure could be used to control thawing around the piles.

(2) Special Type Landing Mat. - A landing mat is visualized which will thaw down at the same rate as the general surface, or which can be moved readily to a new alignment every year or two.

PART VI - SUMMARY OF RECOMMENDATIONS FOR 1956 PROGRAM*

6-01. It is recommended that the existing main road be extended approximately 1-1/2 miles and a transfer point constructed just above the firn line.

6-02. It is recommended that the 1956 program include study of the possibility of constructing a small gravel airstrip in a sufficiently level location near the firn line.

6-03. It is recommended that all future construction on ice surfaces use only free-draining, coarse materials for construction which will be subject to traffic of any kind, except in instances such as deep fills not subject to through seepage where material will be protected from effects of summer thaw by a cover of the desired free-draining materials.

6-04. It is recommended that observations be continued through 1956 of the following studies:

a. Existing experiments in various methods of shoulder treatment.

b. Effectiveness of training dikes.

c. Existing Instrumented test fills.

d. Effect of dust and methods of control.

e. Periodic cross sectioning and movement measurements.

f. Weather records at stations covering the construction area.

g. Records of production rates and equipment performance.

6-05. It is recommended that a study be carried out to determine the proportions of thawing on the ramp caused by direct solar radiation and the proportions contributed from other heat sources for purpose of improving methods of thaw prediction. It is recommended that a program for such study be developed in close cooperation with SIPRE.

* See Appendix C for detailed preliminary recommendations for plan of tests in 1956.

6-06. It is recommended that no reliance be placed on availability of equipment from the Eastern Ocean District in 1956 and that all possible steps be taken to insure the positive availability of sufficient equipment, in A-1 operating condition, and of types suited to the local conditions.

6-07. It is recommended that existing roads be maintained in full operation by construction of berms, addition of drains or such other measures as may be necessary.

6-08. It is recommended that the existing transverse road be continued to the ice tunnel. (However, some study should be given to the alternate possibility of constructing an entirely new direct road from TUTO).

6-09. If the existing transverse road is continued to the ice tunnel, it is recommended that this road be widened from 24 feet to 30 feet.

6-10. It is recommended that the culvert and drainage experiments started in 1955 be continued.

6-11. It is recommended that the experiments in use of steam thawing to artificially thaw potential borrow material, originally planned for 1955, be carried out in 1956, in order that basic information will be available on feasibility of using this method to make borrow materials available during other than the summer thaw season.

6-12. It is recommended that some consideration be given to putting down one or more explorations to 20 feet or more by means of core drilling or test pitting to determine the type of material available with depth.

6-13. It is recommended that at least one pile-supported timber bridge of nominal span be included in the road construction to the ice tunnel, to determine the feasibility of this type of construction.

6-14. It is recommended that an office study and possibly a laboratory study be included in the 1956 program to determine the general feasibility of a special landing mat for use on thawing ice surfaces. If possible, initial field experiments should be performed.

PROJECT I PERSONNEL, GREENLAND 1955

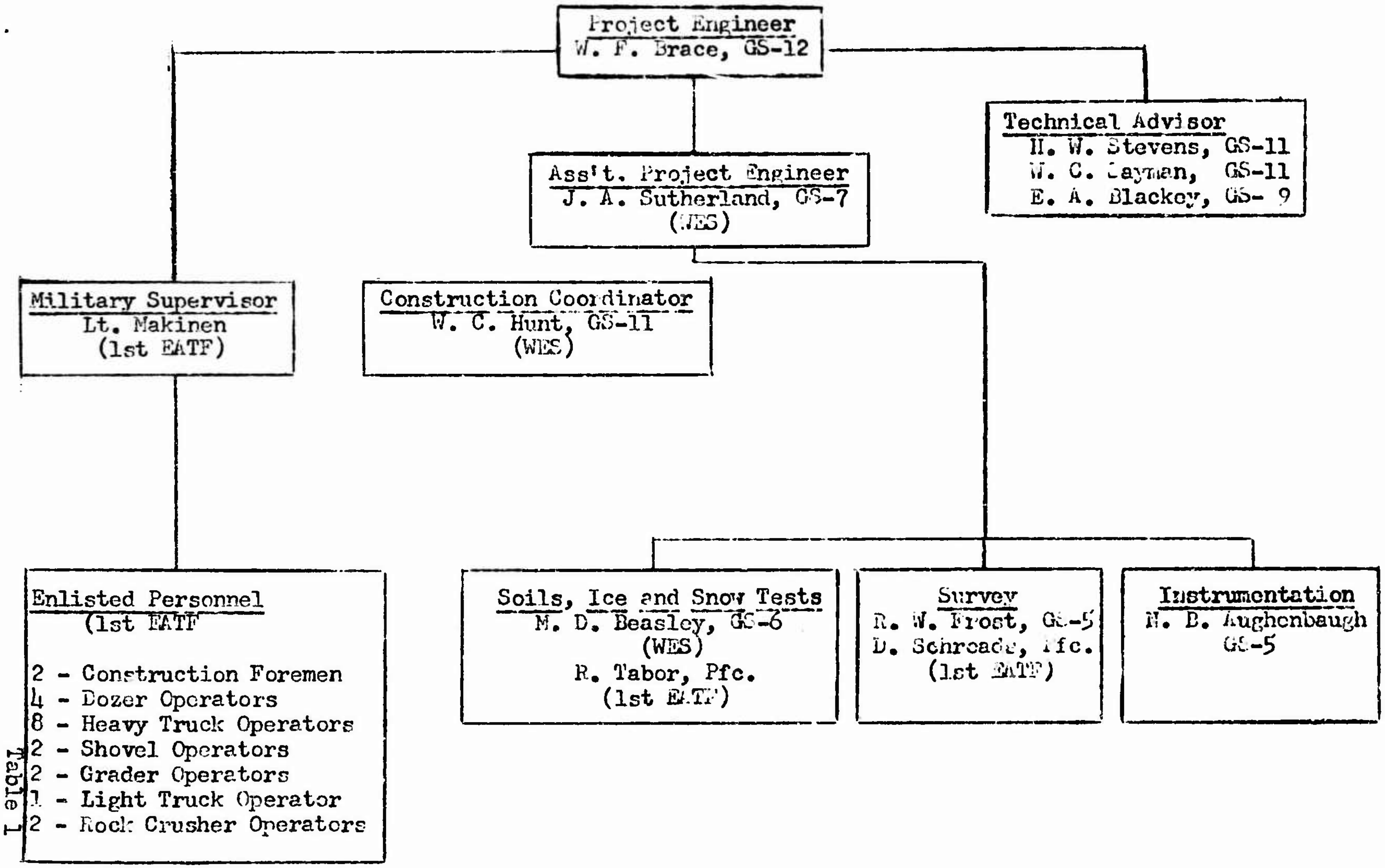


Table 1

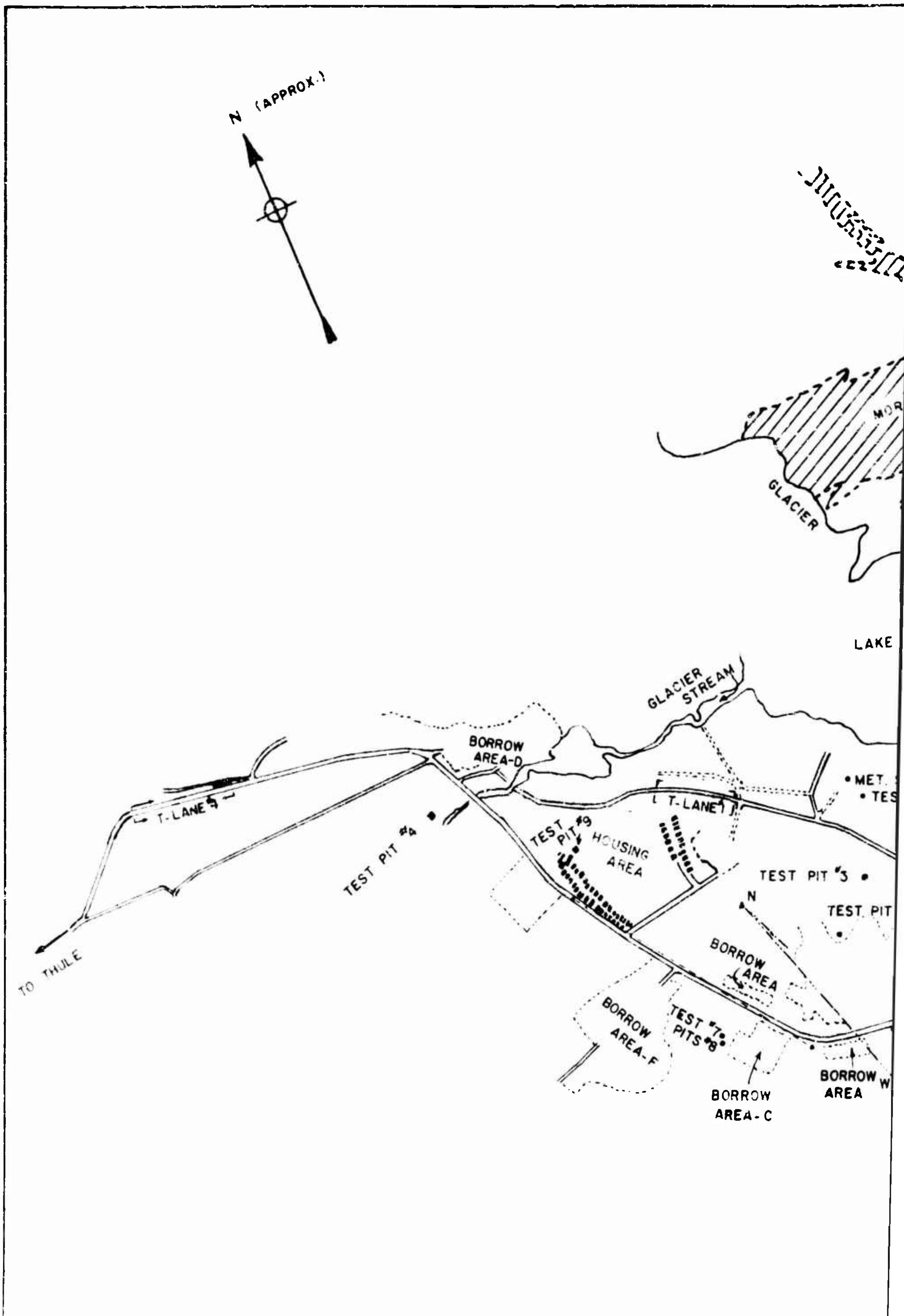
TABLE 2
WORK OUTPUT FOR HEAVY CONSTRUCTION EQUIPMENT

Project	Station	Lineal Feet	Time	Shifts	Yards Placed	Available Equip. Hrs.	Operating Hrs. % Avail.	*Deadline Hrs. in %	**Standby Hrs. in %	Lin.Ft./Shift	Cu. Yds./Shift
Road Rebuilding	31-47	1600	20/6-13/7	20	5,150	2,050	43.5	30.0	26.5	80	310
Transverse Road (24' wide)	0-8	800	12/7-22/7	10	3,150	1,116	49.0	19.0	32.0	65	310
Main Road (30' wide)	47-98	5100	24/7-27/8	53	16,620	4,848	55.0	5.0	40.0	96	311
Project Total		7340 30' wide	68 calendar days	83	24,920	8,004	49.1	18.0	32.9	80.3	310.3

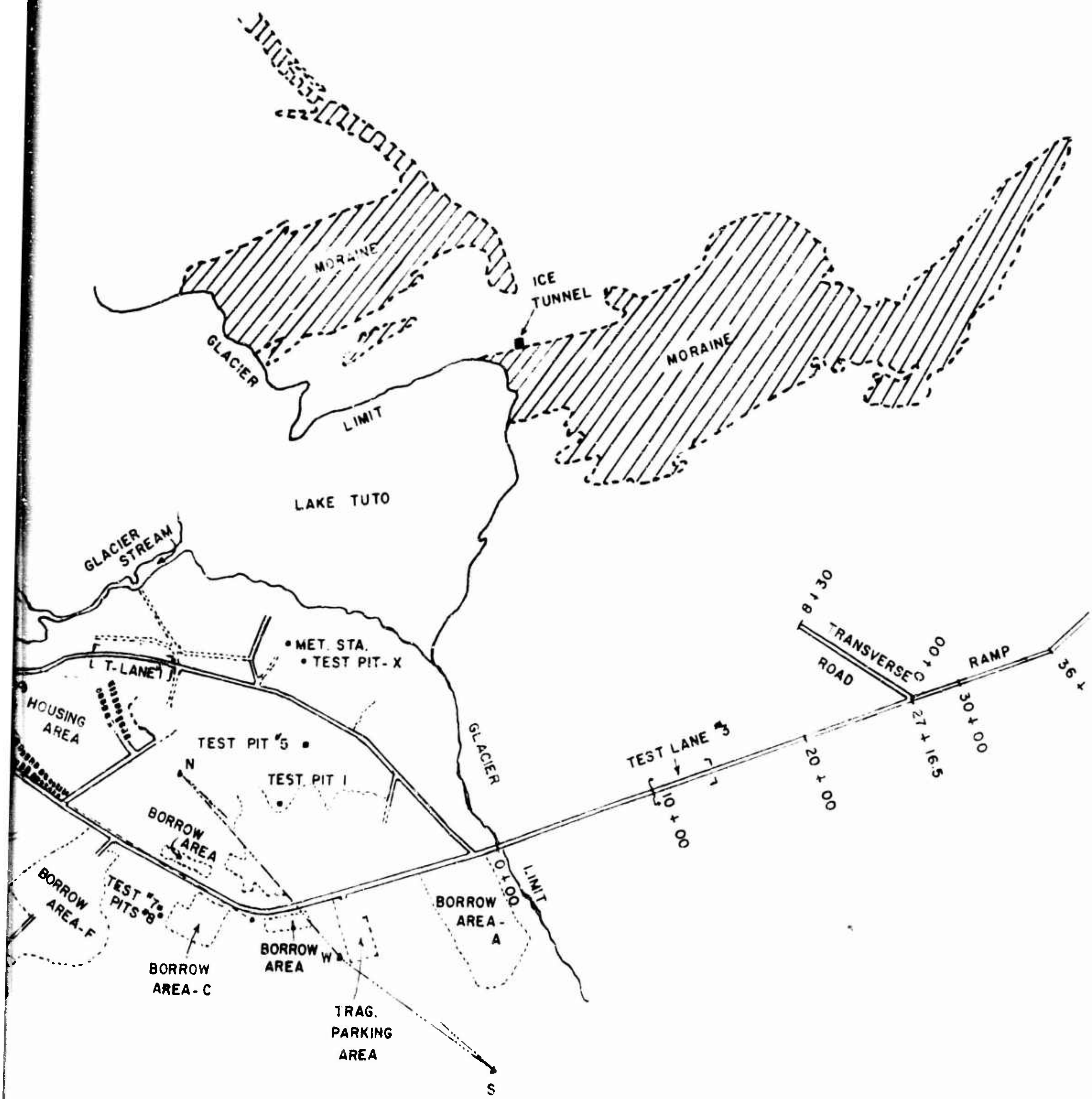
* Deadlined Hrs. = Indicates repair during the standard work week. No maintenance included.

** Standby Hrs. = Indicates (a) lack of operators and (b) on loan to other projects.

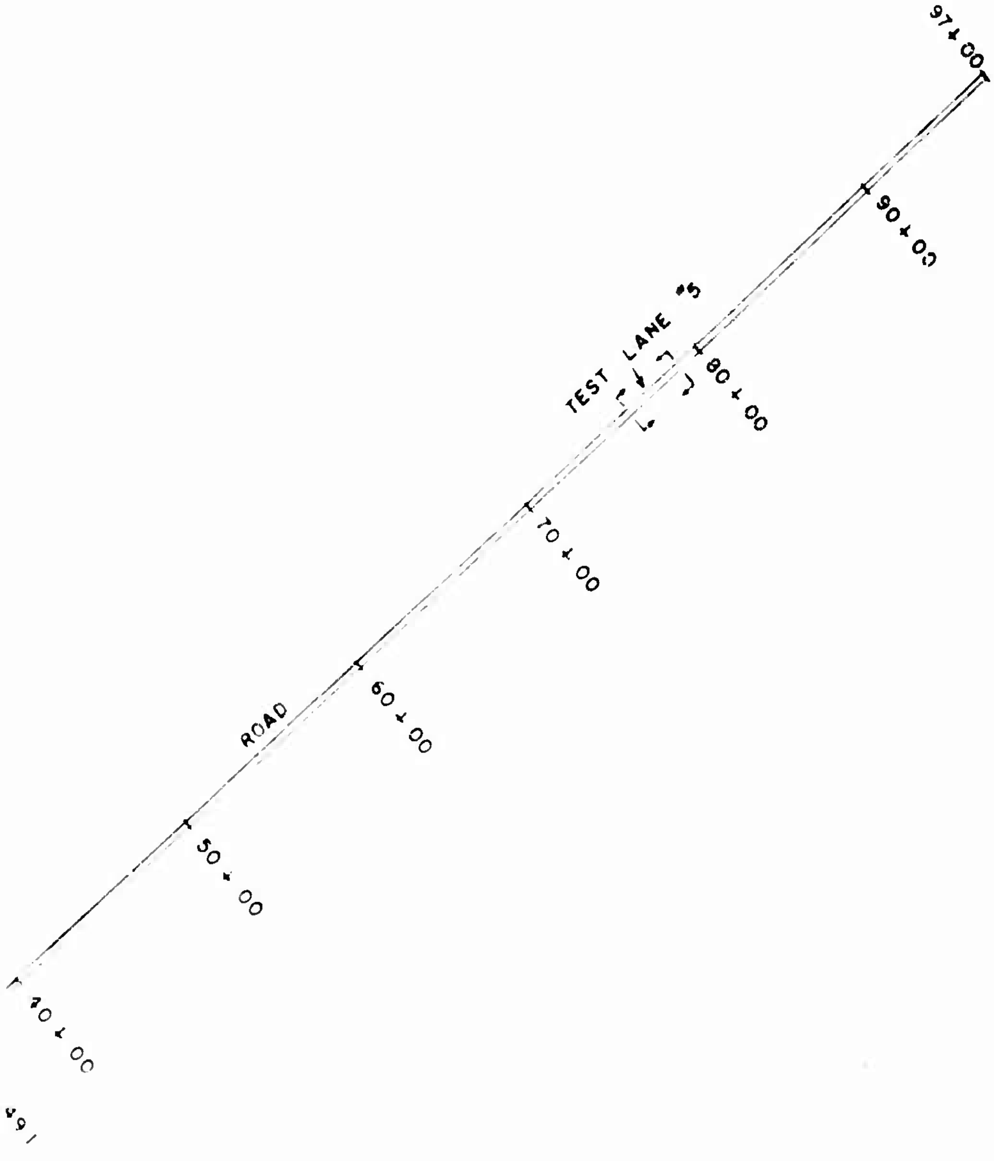
Table 2



N (APPROX.)
MOR
GLACIER
LAKE
GLACIER STREAM
BORROW AREA-D
T-LANE
T-LANE
• MET.
• TES
TEST PIT #4
TEST PIT #9
HOUSING AREA
TEST PIT #3
N
TEST PIT
TO THULE
BORROW AREA
BORROW AREA-F
TEST PITS #7 #8
BORROW AREA-C
BORROW AREA
W



MORAINE
ICE TUNNEL
MORAINE
GLACIER
LIMIT
LAKE TUTO
GLACIER STREAM
MET. STA.
TEST PIT - X
T-LANE
HOUSING AREA
TEST PIT #5
N
TEST PIT I
BORROW AREA
BORROW AREA-F
TEST #7 PITS #8
BORROW AREA-C
BORROW AREA
W
TRAG. PARKING AREA
S
BORROW AREA-A
0+00
LIMIT
GLACIER
TEST LANE #3
10+00
20+00
27+16.5
30+00
RAMP
36+
TRANSVERSE ROAD
0+00
8+30



GREENLAND 1955 PROGRAM

PROJECT I

GENERAL MAP

OF

CAMP TUTO AREA

SCALE: 1" = 800'

PLATE I

APPENDIX A

PLAN OF TESTS

Project 1, Approach Road

Engineer Activities in Greenland for Calendar Year 1955

Revised June 1955

Introduction

1. The Waterways Experiment Station, Corps of Engineers, Vicksburg, Mississippi, was assigned primary responsibility for Project 1, Approach Roads of Engineer Activities in Greenland for 1955. The Arctic Construction and Frost Effects Laboratory, New England Division, Corps of Engineers, Boston, Mass., was requested by Waterways Experiment Station in a letter dated 18 March 1955 to assume the work of planning the tests, conducting the field work and writing the report. The Arctic Construction and Frost Effects Laboratory accepted the work in a 1st indorsement to above letter dated 31 March 1955.

Objective of Project 1

2. The overall objective of Project 1 in 1955 is to determine the feasibility of constructing gravel fill roads on ice and snow surfaces encountered on the Greenland Ice Cap, with the investigations to be conducted in the TUTO area near Thule AFB. The specific objectives of the project are:

a. To continue the construction of the ice ramp road started in 1954.

b. To continue studies leading to design criteria for the construction of gravel fill roads on ice by means of trial tests of road

fills, various types of drainage installations and various methods of retaining slope stability. Records will be made of pertinent soil, ice and snow properties, the thaw penetration, movement of road fills, the trafficability characteristics of roads and the meteorological characteristics of the working area.

Preliminary Survey

3. A preliminary survey and reconnaissance of the existing approach road will be made the first week in May. Observations and rough measurements of the snow conditions and drfiting will be made. Photographs of the most important features will be made.

Plan of Tests for Calendar Year 1955

4. New Construction.

a. Extension of Ramp Road. To meet current operational requirements of the TC Corps, U. S. Army and other interested agencies, as well as to continue investigation of road construction on the ice, the present 4500 feet of road leading up the Ice Cap from the edge of ice will be extended as far as possible in the time available, with the equipment and personnel allotted to the project; estimated to be approximately 1-1/2 miles. The road will have a standard cross section with 30 ft. traveled way and 2:1 slopes. Depth of fill will generally be 2 feet to 2-1/2 feet but may be varied to suit surface conditions encountered. The lower 1 to 1-1/2 feet of fill will consist of coarse gravel and boulders with the top one foot of bank run gravel with a maximum size of approximately 3 inches. Drainage facilities will be provided when and if required.

b. Test Road Transverse to Melt Water Flow. An experimental section of road will be constructed from the existing main ramp road in a northerly direction approximately 800 ft. The road will be constructed according to the same general design as the main road. Depth of fill will generally be 3 feet except as it may be necessary to increase this depth to accommodate surface conditions of snow depths and melt water flow. Where melt water channels cross the road, various types of drainage structures will be installed for test purposes including Armco culverts and inverted drainage types.

c. Test Lanes and Special Test Sections. At least one instrumented test lane having three sections with three depths of fill will be constructed in the main road. The test lane will be located near the firn line if the road is constructed that far. Instrumentation of the test lane or lanes will consist of thermocouple assemblies placed in the fill and in the ice subgrade. Reference plates for the measurement of the amount of ice melt under the fill will be placed in each of the test sections.

Several test sections will be constructed to investigate methods of retaining slope stability endangered by excess melting of the ice surface. These sections will include one with a slope of 4:1, one with a thin blanket of gravel at the toe of slope, one with the slopes painted white and one using snow placed on the slopes.

5. Special Studies. A number of special studies will be conducted leading to the development of design criteria and improved techniques and methods for construction of gravel fill roads on ice and snow surfaces. The following specific studies will be undertaken:

a. Evaluation of the existing roads to determine the effectiveness of the design after subjection to one winter's snow cover and the freezing and thawing of one complete season. The movement of the road laterally, horizontally and vertically, will be determined by periodic cross sections, profiles and location surveys. The bearing capacity of the soil fills and the water content and density will be determined at intervals as the thaw penetrates the fill. Observations will be made of road behavior under traffic during the thaw season.

b. The control of melt water flow will be studied by installing various types of cross-road drainage structures in the transverse road section including Armco culverts and several types requiring no special materials but which might be useful as field expedients. Experiments will be conducted with various methods of diverting melt water flow and the cutting of drainage ditches in the ice. Observation will be made and records kept of the quantity of melt water flow and the performance of the various installations.

c. During the 1954 melting season, an excessive amount of ice melted in the areas at, and adjacent to, the toe of road slopes. Experiments will be conducted to develop methods of preventing excessive ice melting. Experimental test sections will be constructed as described in 4c. Observation will be made and records kept of the performance of the test sections throughout the summer.

d. Studies of the rate and characteristics of thaw penetration in the TUTO area commenced in 1954 will be continued. Areas will be

selected at some distance from the 1954 investigated area where thaw penetration will be measured by means of test pits and with correlating measurements of soil properties. One location will be selected for study in the area stripped in 1954. Thaw penetration will be measured in the fills of the existing road with special reference to the test lanes.

e. Methods of obtaining borrow materials will be studied as well as the characteristics of available materials.

f. A reconnaissance and brief study of the Huna Ramp road will be made to determine if there may be recommendations for the improvement of the road.

6. Records and Data Accumulation. To accomplish the purpose of the project and to properly evaluate the results of test installations, tests of soil, snow and ice properties will be conducted at periodic intervals as necessary. Continuous records will be kept by survey methods of road movement and settlement as well as as-built data for all installations. Weather data will be recorded throughout the working season and subsurface temperatures measured by the thermocouple installations made in 1954 and the additional installations to be made in 1955.

a. Soil tests contemplated will include the following:

(1) Water content and density measurements in the undisturbed ground in connection with thaw penetration measurements. Tests will be required on thawed and frozen soils.

(2) Water content and density measurements in the road and test lane fills in connection with thaw penetration studies and bearing capacity evaluation.

(3) In-place CBR tests on road fills to determine bearing capacity versus seasonal changes. Cone penetrometer tests will be conducted where applicable.

(4) Grain size analysis including hydrometer tests and Atterberg limits where applicable to allow identification and classification of all types of soil encountered.

b. Snow and ice tests will include CBR, compaction, density and grain size and will be conducted as necessary to record conditions where construction involves the use of these materials.

c. Survey measurements will generally consist of the following:

(1) Establishment of bench marks, base lines, stationing, grade stakes, etc., as necessary to maintain control of construction operations and provide basis for as-built records of installations.

(2) Periodic cross sections and profiles of roads and test installations as necessary to record depths of snow, melting of ice surface, character of road surface, etc., and including levels on reference plates in test lanes.

d. Temperatures and other weather data will be regularly recorded throughout the field season. Subsurface temperatures will be measured by means of the thermocouple installations made in 1954 and any installed in 1955. Air temperatures will be measured by three recording

thermographs, one located on the Ice Cap, one at TUTO camp and one at the intersection of "P" Mtn. road and the TUTO approach road. In cooperation with SIPRE, who will have several parties located in the TUTO area, measurements will be made of wind-speed and direction, relative humidity and air temperature.

Report

A report summarizing the results of the field work will be prepared after completion of the field work in Greenland.

APPENDIX B

PACKING LIST

Project 1, Greenland 1955 Program

ACFEL

No.	Item	Contents	Weight	Cube
1	Box	Coring Auger complete with: 2 - cutting shoes w/leather covers 1 - coring auger barrel 1 - sample remover barrel 1 - cap 8 - drill rods, 3 ft. 2 - drill rods, 2 ft. 1 - ice chisel, to fit drill rods 1 - ice spoon, to fit drill rods 1 - brace, for ice coring auger 1 - tee handle 1 - ice pick 1 - sheath, ice pick 2 - screw drivers, 1 large, 1 small 1 - hammer, piton 1 - socket wrench handle with: 1 - 3/8" long socket 1 - 5/8" short socket & universal swivel 1 - rule, metal, 6' 1 - file, oval tapered 1 - offset screw driver 2 - wrenches, stilson, 10" 1 - pack frame 1 - canvas carrying case	119	5
2	Box	Non-coring Auger with: Auger 10 - drill rods, 3 ft. 1 - swab 2 - 40"plastic tubes, 3/4", with caps 6 - settlement plates with attached flanges 2 - 18" plastic tubes, 3/4" with caps 2 - 30" plastic tubes, 3/4" with caps	69	2

No.	Item	Contents	Weight	Cube
3	Box	Power Auger with: McCulloch motor Spare parts Chain Saw adapter Chain Saw blade Chain Saw 1 - Auger adapter 1 - "E" rod air adapter 1 - Swivel hose connection 1 - 6" earth auger with cutting blade, depth of cut adjusting plates & "E" rod adapter 2 - "E" rods, 18"	222	12
4	Box	Thermocouple assemblies in plastic tubing 10 ea. - 15 ft. 4 ea. - 30 ft. 6 ea. - for subsurface temperatures 100 ft. coil - thermocouple wire 1 roll plastic tape for splicing 1 Bag pipe fittings for thermocouples 4 - reducing elbows, 1-1/2" x 1" 2 - reducing elbows, 1-1/2" x 1-1/4" 6 - unions, 1-1/2" 5 - couplings, 1-1/2" 1 - coupling, 1"	245	20
5	Box	Panel boxes w/box, panel & fittings 3 - 18 point 3 - 24 point	188	6
6	Bundle	Pipe for thermocouple assemblies 8 - 1-1/4" x 6 ft.	114	2
7	Bundle	Pipe for thermocouple assemblies	104	2
8	Box	2 - Snow grain size cups 1 - magnifying glass 3 - snow density samplers 1 - pocket transit (Brunton compass w/case) 1 - hand level 1 - line level	125	5

No.	Item	Contents	Weight	Cube
		5 - dial thermometers		
		1 - qt. thermos bottle		
		6 - field books		
		Reference Manuals and Computation pads		
		2 - aluminum clip boards		
		200 - Thermocouple Reading Forms		
		1 - Anemometer w/case		
		1 - 50ft. metallic tape w/case		
		5 - radiation shields		
		2 - stop watches		
		1 - Camera (Medalist) w/case		
		Lens cover		
		Cable release		
		Accessory back		
		2 - Film pack adapters		
		1 - Filter carrying case with:		
		1 - K2 filter		
		1 - Sky filter		
		1 - 81c filter		
		1 - Lens hood		
		1 - +2 Portrait lens		
		1 - Leather carrying case		
		1 - Optipod Camera holder		
		1 - Exposure meter		
		Film as follows:		
		8 - 2-1/4"x 3-3/4" film packs, B & W		
		15 - 35mm kodachrome		
		6 - 35mm B&W		
		9 - 620 Ecktachrome		
		20 - 620 B&W		
9	Box	1 - Barrel pump for spray painting	45	2
		1 - Brace for non-coring auger		
		3 - prs. rubber gloves		
10	Box	Steam Thaw Equipment	295	5
		30 - 3/4"x6-1/2 ft. steel pipe		
11	Box	30 - 3/4"x3-1/2 ft. steel pipe	157	2
		29 - 1-1/2"x4" nipples		

No.	Item	Contents	Weight	Cube
12	Bag	1 - 1-1/2"x4" nipple 50 - 3/4" couplings 14 - 1-1/2"x3/4" reducing tees 3 - 1-1/2"x1-1/4" reducing 90° elbows 3 - 1-1/4"x3/4" reducing bushings	94	2
13	Bundle	3 - 26' lengths of 1-1/2" explosion proof steam hose with fittings attached each end	210	8
14	Bundle	4 - 6ft. lengths of 1-1/2" explosion proof steam hose with fittings attached each end	106	4
15	Bundle	Same as bundle No. 14	106	4
16	Bundle	Same as bundle No. 14	106	4
17	Box	9 gals. masonry paint	128	3
18	Box	12 gals. masonry paint	175	4.5
19	Box	4 gals. masonry paint 25 - pounds masonry paint (powder)	109	4
			2717	96.5

WES

No.	Item	Contents	Weight	Cube
1	Box	1 - Plate 10# surcharge 8 - 12" Extensions 2 - 4" Extensions 2 - 2-1/2" Extensions 1 - Penetration piston 1 - Piston Adapter 1 - Jack and Handle 1 - Level, carpenter 1 - Can oil for jack 1 - Trowel 1 - Dial Extension clamp 1 - Knife 1 - Straight edge 1 - 10" Pipe wrench 1 - 14" Pipe wrench 2 - Open end wrenches 2 - Cans 3-in-1 oil 2 - Proving rings 3 - Dials (extra) 3 - Toilet tissue	142	2.8
2	Box	1 - Scales kilo 2 - Weights, 2-kilo 1 - Weights, 5-kilo 1 - Weights, 10-kilo 1 - Weights, 1-kilo	97	3.9
3	Box	2 - Jack handles 1 - I-Beam, for mounting jack 1 - Beam, penetration 2 - Locks (beam to truck) 3 - 20# surcharge weights 1 - 10# surcharge weight 2 - 30" chisels 1 - Drive head (for density cylinders) 1 - Hydrometer	197	4.2
4	Box	1 - Sand density cylinder 1 - Sand density plate 3 - Spoons 1 - Hand blower 1 - Paint brush	85	2.8

No.	Item	Contents	Weight	Cube
		1 - Spatula		
		1 - File		
		1 - Hammer, machinist		
		1 - Battery filler		
		3 - Chisels		
		5 - Pkg. moulding clay		
		20 - Cans (for limits)		
		1 - Box 5-H pencils		
		2 - Rolls drafting tape		
		2 - Box China marking pencils		
		3 - Box paper clips		
		3 - Cans 3-in-1 oil		
		6 - Rolls Scotch tape		
		1 - 100' tape		
		1 - Bottle ink		
		2 - Soap, hand		
		2 - 6' steel tapes		
		1 - Box rubber bands		
		1 - Wire cutters		
		3 - Screwdrivers		
		1 - Remolding hammer		
		1 - Pliers		
		1 - 6" crescent wrench		
		1 - Pliers, sharp nose		
5	Box	2 - Track jacks	178	2.9
		2 - Soap powder		
		1 - First Aid Kit		
6	Box	1 - Oven	143	8.6
		1 - 5-gal. cans		
		1 - 1-gal. can		
7	Box (A)	1 - Scales, and weights (500 grams)	207	7.7
	(B)	24 - Moisture cans		
		2 - Wrenches (for remolding hammer)		
		1 - Penetrometer w/handle		
		1 - Penetrometer dial (extra)		
		1 - Hand level		
		2 - Soap, hand		
		3 - Books, field		
		1 - Remolding form (5.5)		
		2 - 1/2" cone		

No.	Item	Contents	Weight	Cube
7	Box (B) cont'd.	2 - 1" cones		
		Cone index forms		
		Field note forms; Small sheets		
		Moist Density Forms.		
		1 - Pkg. carbon paper		
	(C)	2 - Bottles ink (for Thermograph)		
		12 - Drive cylinders		
		1 - Airfield penetrometer		
		1 - Oven thermometer		
		2 - 100 cc graduates		
		2 - Thermometers (hydrometers)		
		1 - Stereoscope		
		1 - Box Keel		
	(D)	11 - Evaporator dishes		
		1 - Triple Beam scales		
		1 - 500 cc Snow density cylinder		
		1 - Voltage regulator		
		1 - pkg. CBR forms		
		1 - Pencil sharpener		
		1 - pkg. Bond paper		
		4 - Legal size pads		
		4 - Letter size pads		
		6 - Boxes 4-H pencils		
		Density data sheets		
		Grain size sheets		
		Moisture content forms		
		Atterberg limit forms		
		Sand density forms		
		Graph paper		
		Air Mail Envelopes		
		4 - Penetrometer staffs		
		1 - Remolding handle		
		1 - Laboratory tongs		
		1 - Carpenters hammer		
		3 - Clip boards		
		6 - File folders		
		Thermograph charts		
8	Box	1 - Sieve shaker	90	3.8
		1 - Set Sieves (1-1/2", 1", 3/4", 1/2", 3/8", 1/4", 4, 10, 40, 60, 100, 200)		
		1 - Gallon bucket		

No.	Item	Contents		Weight	Cube
9	Box	1 - File 3 - Thermographs		105	5.9
10	Box	1 - Instrument Shelter		105	16.0
11	Box	1 - Instrument Shelter		105	16.0
12	Box	1 - Instrument Shelter		105	16.0
			WES	1559	90.6
			ACFEL	2717	96.5
			Total	3276	187.1

APPENDIX C

PRELIMINARY RECOMMENDATIONS FOR PLAN OF TEST PROJECT 1, APPROACH ROAD, 1956 ENGINEER ACTIVITIES IN GREENLAND

1. OBJECTIVE. - The over-all objective of Project 1 in 1956 will be to continue the study of the feasibility of constructing gravel fill roads on ice and snow surfaces encountered on the Greenland Ice Cap, with the investigations to be conducted in the area near TUTO, Thule Air Force Base, Greenland. The specific objectives of the project in the summer of 1956 will be:

a. To continue construction of roads started in 1954 and 1955.

b. To continue investigations related to the road construction, leading to development of design and construction criteria.

2. PRELIMINARY SURVEYS AND OBSERVATIONS. - During the winter of 1955-1956, First Engineer Arctic Task Force personnel will read thermocouples installed in the summers of 1954 and 1955 at intervals as feasible. Commencing 1 March 1956, the Task Force will take readings once every two weeks until the summer program is started approximately in June.

A preliminary survey and reconnaissance of the condition of the roads in the TUTO area will be made approximately the first week in May of 1956. Observations and rough measurements of the snow conditions and drifting will be made and photographs of the most important features will be obtained.

3. 1956 CONSTRUCTION PROGRAM. - In planning a program of investigations in the TUTO area for the summer of 1956, two aspects have been considered: (1) the maintenance, improvement and preservation of existing roads; and (2) new investigations and installations, including the construction of new sections of road. In practically all cases, the activities to maintain, improve and preserve the existing roads and to build new sections of road for investigational purposes will serve local operational needs in addition to being of research value.

a. Maintenance, Improvement and Preservation of Existing Roads. - From both the operational and investigational standpoints, the measures proposed under this heading are considered to be very important. The present main ice ramp road is at present heavily depended upon to provide access to the upper portion of the ramp for vehicles. The following measures are recommended:

(1) Stations 0+00 to 30+00. - This portion of the existing road has gone through two thaw seasons and has been subjected to summer thawing temperatures more intense than on any other part of the road construction on ice. It is doubtful that the shoulders of this road will remain stable through another thaw season. With modifications to the design, however, it is considered the road may be maintained for several years. It is recommended that the following alternative methods be considered:

(a) Construct berms of 50 ft. minimum width on each side of the present road.

(b) Bulldoze aside bouldery fill of the present road, using the material to construct berms of 50 ft. minimum width on

each side of the centerline. Leave part of the existing material or replace it with new material, such that the centerline will have a reduced depth of fill. It is desirable that the road fill in this location remain elevated above the general level up to as much as 5 ft. in order to remain above the accumulated deep winter snow. Now that an ice pedestal has been formed along the centerline of the road through this area, it is believed that a maximum fill of two feet will now provide this desired road elevation.

(c) Relocate the road, constructing a new road complete with berms.

Pending further study, method (a) above is tentatively recommended.

(2) Stations 30+00 to 76+00. - This section of road was practically entirely reconstructed in 1955. Results from installation of training dikes and berms for experimental purposes in this section in 1955 were sufficiently favorable so that it is recommended that this entire section of road be furnished with berms and melt water control dikes, exact location and design to be determined after study of the observations made in 1955, and in the field during construction. It is tentatively recommended that berms be installed to a width of approximately 50 feet, and that training dikes be extended some distance beyond in order to assure that no heavy melt water streams would develop in the vicinity of the road.

(3) Stations 76+00 to 98+00. - This section of road is not subjected to as intense thawing conditions as the lower section of the road and the need for protection against excessive thawing is not

as critical. A few dikes for diversion of surface flow were constructed in 1955, and it is recommended that the development of melt be observed closely in the next year to determine the performance of the existing dikes and the possible need for dikes and berms.

(4) Transverse Road, Stations 0+00 to 8+00. - This road should be widened from the present 24 foot width to 30 feet, if it is to be used for other than experimental purposes; that is, as an access road to the ice tunnel. Fifty foot wide berms should be added on the shoulders. The existing culverts will probably no longer function because of their perched position and should require no attention or construction.

b. New Construction.

(1) Materials. - It is recommended that new construction use only coarse free-draining materials.

(2) Extension of the Main Road. - The existing road as completed in 1955 has reached an elevation on the ice ramp at which the melting of the ice surface during the summer is distinctly less than at the lower end of the road. However, the road has still not reached the zone on the Ice Cap where the net yearly accumulation of ice or snow begins to become appreciable. It is presently considered that the optimum location for construction of gravel fill roads on ice and snow is near the firn line where the road will not become progressively buried under annual accumulations, yet the thawing of the ice adjacent to the road will be a minimum.

Accordingly, it is recommended that the main road be extended a distance of approximately 1-1/2 miles or to just above the firn line

and a load transfer area be constructed at the terminus. The necessity for protective berms and lateral dikes may not be present at the higher elevations, but this can only be determined in the field from observation of road performance during the thaw season. The design of the road should follow that used in 1955 unless it should be found necessary to modify it during the work season, as the results of observations on test sections built in 1955 become available. The road should have a standard cross section with 30 feet travelled way. The fill, exclusive of berms, should be approximately 2 feet but may be varied to suit surface conditions encountered. The lower 1-1/2 feet of fill should consist of coarse, free-draining, gravelly or bouldery material with a top dressing of a few inches of crusher run fine gravel or similar free-draining material. Drainage facilities should be provided if required.

One additional experimental test section, using about three fill thicknesses appropriate to the climatic conditions, should be included near the end of the extended road, in order to cover an additional thaw condition.

In construction to date, it has been the practice to bulldoze aside the snow overlying the hard ice space before placing the gravel fill. It is recommended that in 1956 the fill be placed directly on the existing snow surface without removal, where the snow depth does not exceed about 2 feet. This will save the substantial effort required for bulldozing this snow aside, and it will also improve the drainage situation by eliminating the large banks of snow which affect the local drainage near the road during the thawing season. It is also possible that at the higher elevations these bulldozed banks of snow may not melt

completely during the thawing season, in which case they may induce an undesirable snow drifting situation during the winter.

It is recommended that at the start of the construction season a few experimental sections be constructed parallel to the road using various thicknesses of fill, such as 6 inches, 12 inches and 18 inches for short sections in order to determine the minimum thickness of fill which can be effectively placed over the existing essentially dry snow cover. It is recommended that these experimental sections be trafficked to determine the minimum thickness of such fill capable of carrying military traffic trucks. These experiments will provide information of value in case it is necessary to construct gravel roads over snow surfaces under emergency winter conditions.

It is recommended that field reconnaissance be made in 1956 to determine a suitable location where the main road may be widened sufficiently for construction of an experimental small air strip or where a separate gravel air strip can be built. A recommendation should be made at the end of the 1956 season as to whether or not such an air strip should be built and as to its specific location.

(3) Road to Ice Tunnel. - It is considered that the most feasible method of gaining satisfactory access to the ice tunnel is by construction of a gravel road, either by extension of the experimental transverse road constructed in 1955 or by construction of an entirely new road on a more direct alignment from the TUTO camp area. It is recommended that choice between these two possibilities be made during the winter of 1955-1956 based on study of various possible alignments.

While considerable quantities of material, man-hours and equipment hours are involved, it is considered that valuable experience would be gained in the construction of roads across a rougher terrain than has been encountered on the main ramp. The design of such a road should be similar to that used in the 1955 construction season with a highly permeable boulder base. Depth of fill should be generally 2 feet, except as it may be necessary to increase this depth to accommodate surface conditions of snow depth, melt water flow or grade. Where melt water channels cross the road, various types of drainage structures should be installed for test purposes; however, it is recommended that the basic type of culvert for smaller streams on ice should be a semi-circular Armco section, without bottom.

It is recommended that at least one short pile-supported bridge be constructed across one of the deeper thaw channels, with the floor structure designed to shade the piles from the sun so far as possible.

Careful planning of this road will be needed to insure a feasible design across sloping ice surfaces, large drainage streams and moraine formations. Careful planning will also be needed for bridges, culverts, etc., in order to insure that required materials and equipment will be available.

c. Further Test Sections and Field Experiments. - When the results of the 1955 tests are analyzed, and as observations are being made in the 1956 season of the performance of the test sections, new methods will undoubtedly suggest themselves. Additional test sections to investigate these approaches should be constructed. However, approval

of any substantial field changes in the Plan of Test should be obtained before work is initiated.

4. TIME-QUANTITY-ESTIMATES FOR PROPOSED 1956 PROGRAM. - A rough estimate of quantities and time involved in the proposed 1956 program has been prepared as shown below. The time figures are based on progress in the 1955 season and are representative of time required using equipment equal to that available in 1955. Allowance has been made for such factors as increased length of haul, and construction of culverts, bridges, etc. No allowance has been made for the time or extra material involved in the construction of test sections, as it has been found that a limited amount of this type of work can be accomplished without appreciably interfering with the over-all construction progress.

Item	Yardage	Time
Construction of 50' berms on both sides of the road Sta. 0+00 to 30+00	10,000 cu. yds.	32 shifts
Construction of a 50' berm on both sides of the road 30+00 to 76+00	8,500 cu. yds.	28 shifts
Widen the present transverse road to 30'	5,300 cu. yds.	17 shifts
Extension of main road to 185+00	25,770 cu. yds.	83 shifts
Extension of transverse road to ice tunnel (approx. 3,000')	8,300 cu. yds.	27 shifts
TOTALS	57,870 cu. yds.	187 shifts

It may be noted that the completion of the entire program would require approximately 94 working days. Considering that one day a week is required for rest for the equipment operators and for maintenance of equipment, the working season is not usually long enough to provide this number of working days.

5. EQUIPMENT REQUIRED TO COMPLETE ENTIRE PROPOSED 1956 PROGRAM. - The program recommended for 1956 requires the handling of more than twice the yardage moved in 1955. Unless considerable additional equipment and man-hours are available, beyond those provided in 1955, the entire program cannot be completed.

It is obvious, therefore, that for the 1956 program either additional equipment must be provided or the construction program must be reduced to a reasonable amount, based on the equipment available at the close of the 1955 season. In 1955 some of the more critical pieces of equipment were obtained on loan from other organizations, an unsatisfactory situation due to the uncertainty of obtaining the items until actually in the field. These organizations cannot generally commit their equipment until they are assured that they will not require it themselves. At the close of the 1955 season, the First Engineer Arctic Task Force received an assignment of equipment which will make it possible to have on hand equipment at least equal to that of 1955, with the exception of one or two items (for example, a grader) without borrowing. However, unless additional equipment was received after the Project 1 personnel had returned to the U.S.A., the total equipment needed for the completion of the entire proposed 1956 program is not presently on hand in TUTO.

The following table lists the equipment needed to accomplish the entire proposed program with the exception of test equipment. It is estimated that the number of shifts required to accomplish each phase as listed above could be reduced by one-half if the following equipment were available, complete with necessary operating personnel:

Heavy Equipment Required for Project 1
1956 Program at TUTO Greenland

2 Shovels, 1-1/2 or 2 yd. capacity, crawler type
7 D-8 Bulldozers, including 2 with angle blade
10 8 to 10 yd. capacity Mack or Euclid Trucks
2 Graders, 12' blade
1 Rock crusher, 50 yd. capacity, with secondary crushing unit and screens
1 Lowboy trailer for hauling equipment from job sites
1 Water Truck for sprinkling road
1 Wobble wheel roller, with rubber-tired prime mover
3 Jeeps
1 3/4-ton, personnel carrier
1 2-1/2 ton truck for use as lubricant truck and general servicing
1 Wagon drill
1 Loading unit for rock crusher: 3/4 yd. shovel or D-8 front end loader
1 D-6 front end loader for handling crushed rock stockpiles
1 Compressor with jackhammer and assorted tools
1 Cleaver - Brooks, 3 car, Tank car Heater for steam thawing

From the construction standpoint, the most important items listed, which are in addition to the equipment used in 1955, are the large shovels and the number of large trucks. The addition of a single 1-1/2 or 2 yard shovel would increase production over that of 1955 by a considerable amount.

6. SCHEDULE OF CONSTRUCTION WORK. - The various phases of the construction program require careful timing in relation to the progression of the thaw season. Exact dates cannot be established because of the variation in climate from year to year and in this respect the scheduling must allow a flexibility of as much as 2 to 3 weeks. On the other hand, a greater efficiency is obtained if the timing of the various types of construction is coordinated with such factors as depth of snow and development of melt water runoff.

a. Construction of Berms on Existing Road. - In the winter the snow drifts level with the road surface. In the lower portion of the road, this results in snow depths of 4 to 8 feet. When thaw becomes intense, deep slush results for a time at the toe of the ramp. Therefore, construction of 50 ft. berms in this part of the road must await the melting of snow down to a depth of a foot or so, when it will be feasible to operate equipment on the ice and place gravel. Somewhat higher on the road, the maximum snow depths will be only of the order of 2 to 3 feet and less some distance from the road, so that construction can start earlier than in the lower section of road. Unequal settlement may require trimming of the berm slopes later in the season to insure proper drainage.

b. Road to Ice Tunnel. - The construction of the road to the ice tunnel would be simplified if start of work could be delayed until after the melt water channels become well defined and the deep snow in the large channels has melted. However, the time required to build this road will be so long that it may not be practical to wait until the thaw has progressed as far as desired. Further, it will be possible to locate the positions of the principal thaw channels even in deep snow, using survey data compiled in 1955. It is therefore recommended that construction be carried on without waiting, placing fill directly on the snow, except where removal down to ice may be more practical.

c. Extension of Main Road. - The construction of the extension of the main road would be the most feasible phase of construction to carry on in the early part of the season. The winter snow cover at the higher altitude on the ice ramp does not ordinarily occur over two

feet deep and is usually less. It is believed practical to place the road fill directly on this thickness of snow. As a less desirable alternative, this amount of snow can be plowed aside without too much difficulty.

d. Construction of Test Sections. - Test installations constructed to investigate methods of controlling melt water flow or of preventing ice surface melt should be built as soon as possible, in the season, to allow observance of their performance through as long a portion of the thaw season as possible.

7. SOIL TESTS. - Tests of soil properties should be carried out at periodic intervals as necessary including the following:

a. Water content and density measurements should be made in the undisturbed ground in connection with thaw penetration measurements. Tests should be made on both thawed and frozen soils.

b. Water content and density measurements should be made in the road and test lane fills in connection with thaw penetration studies and with bearing capacity (CBR) evaluations versus seasonal changes. Cone penetrometer tests should be conducted where applicable.

c. Identification and classification tests should be performed on all types of soils encountered, as applicable, including sieve, hydrometer and Atterberg limit tests.

8. SNOW AND ICE TESTS. - In connection with placement of gravel fill directly on snow surfaces, tests should be performed to record the properties of the supporting material, including CBR, cone penetrometer, density and grain size. These should cover the properties of the undisturbed snow and of the material with time after disturbance.

9. <u>SURVEY MEASUREMENTS</u>. - Survey activities should consist of the following:

a. Bench marks, base lines, etc. must be established as necessary to maintain control of construction operations and to provide basis for as-built records of installation.

b. Periodic cross sections and profiles of roads and test installations should be obtained as necessary to record depths of snow, melting of ice surface, character of road surface, etc., including levels on reference plates set at base of gravel fill in test lanes.

c. It is essential to know what road movements are taking place due to movement or flow of the underlying ice in order that accurate conclusions may be drawn as to the effects of various thicknesses of road fill on ice melt by comparison of annual changes in elevation on selected cross sections. That is, if a given embankment station moves downslope several feet in a year, there will be a general change in elevation of the cross section, which must be distinguished from that caused by ablation of the surface in that section. The occurrence of lateral movements of the road should also be known. While some progress has been made in 1955 towards obtaining these measurements, it has been found that an adequate investigation requires more equipment, manpower and organization than has yet been applied. The following requirements are contemplated:

(1) The assignment of a separate and fully equipped survey party to the task.

(2) The establishment of stable, permanent triangulation stations and bench marks from which elevations and base lines can be

obtained from year to year without introducing unknown errors due to movement of the reference points or stations.

10. TEMPERATURES AND ALLIED DATA. - Temperature and other weather data should be recorded regularly throughout the field season. Air temperatures should be measured by several recording thermographs, one located at the intersection of "P" Mountain Road and the TUTO Approach Road, one at TUTO camp, and two or more located on the Ice Cap. In co-operation with SIPRE, which is expected to have several parties located in the TUTO area, measurements should be made of wind speed and direction, relative humidity, barometric pressure and air temperature.

Ground surface and subsurface temperatures should continue to be measured at the thermocouple installations made in 1954 and 1955.

It has been known for some years that predictions of summer thaw penetration in earth fills and under pavements in far northern latitudes, such as the Thule Air Force Base area, may be in error as much as two to three hundred percent if computations are based solely on air temperatures. Again, thaw is observed to start in the spring as much as a full month before the average daily air temperature rises to 32°F. The principal cause of this discrepancy is that current methods of predicting freeze and thaw do not take the radiation factor into account. In very high latitudes summer solar radiation has an extremely important effect on depth of thaw penetration. Some measurements of the contribution of solar radiation in the TUTO area were made by Dr. Schytt and his group in 1954, in a SIPRE study. However, no instruments were available for such measurements in 1955 and no radiation data were obtained. Since it is very important to be able to make reasonably accurate

predictions of summer thaw penetration in connection with construction in these far northern areas, it is recommended that a complete study of all the factors contributing to the freeze-thaw balance be initiated in the TUTO area during 1956. Data should be obtained from both land and ice areas. It is recommended that this program be developed in close cooperation with SIPRE.

11. MEASUREMENTS OF THAW PENETRATION. - The studies of the actual rates and characteristics of thaw penetration in various active zone materials in the TUTO area commenced in 1954 should be continued to the extent indicated by analysis of the 1954 and 1955 results. While the principle measure of thaw penetrations will be subsurface thermocouple readings, occasional test pits and probings are required to confirm and extend these measurements.

12. DRAINAGE STUDY DATA. - Effectiveness of culverts, training dikes and bridges should be recorded.

Data should be recorded on widths, depths and slopes of principle streams and velocities and quantities of flow.

Records should be kept of rates of erosion resulting from stream flow. These should include photographs.

13. EFFECT OF DUST. - Analyses of the effect of dust on the ice surface started in 1956 should be continued. Distribution of dust with distance from road centerline should be recorded. Correlation of dust concentration with observed thaw degradation should be attempted.

14. ROAD PERFORMANCE OBSERVATIONS. - Observations of the traffic and general performance of all roads and test fills in the TUTO area should be continued in 1956.

In 1955 one helicopter reconnaissance of the NUNA Road was made. In 1956 surveys of the local roads should again be made, including not only the NUNA road but also roads near Thule Air Force Base. These surveys should be made relatively early in the season, before appreciable summer maintenance can be accomplished and while roads are in poorest condition because of relatively shallow depth of thaw.

15. INVESTIGATION OF AVAILABILITY OF BORROW MATERIALS. - Results of this phase of the investigations are considered to have a broader application than simply the procurement of materials for the construction of the ramp roads at TUTO. Conditions may arise in which construction must be carried out during seasons when borrow sources are completely frozen, or in which borrow sources are limited in area and it is necessary to consider excavation to substantial depth in permafrost. It is therefore recommended that the 1956 program consider inclusion of the following investigations:

a. Core Borings. - If a situation should arise in which it is desired to consider excavation with depth in a potential borrow source, it would be essential to determine by some type of exploration the type of soil present with depth. In soils containing gravel, cobbles and boulders, such as in the TUTO area, this is difficult if exploration is required beyond a depth of about 10 feet in which range pits may be excavated fairly readily by blasting and bulldozing. It is therefore suggested that consideration be given to putting down one or more core borings to 20 feet or more with the objectives: (1) of determining most suitable methods of making such borings in coarse-grained soil deposits containing ice, or in soil foundations containing ice, (2) of determining

what conditions would be encountered if the local TUTO borrow areas were to be worked with depth, (3) of providing correlation data for steam thawing experiments, and (4) of providing information of value in determining the local geological history.

The key requirement of such explorations would be the recovery of cores in which the ice lenses are sufficiently intact to give an accurate evaluation of the amount of settlement and amount of water release which would occur on thawing. A requirement which is almost as important is that the drilling equipment be as lightweight and portable as possible in order that it will be possible to fly such equipment in to remote sites. However, the first of these requirements is the one of immediate concern.

b. Test Pit. - If a core boring study as recommended above is not included in the 1956 program it is recommended that at least one test pit be excavated to about 20 feet in conjunction with the steam thaw tests for accurate evaluation of the soil and ice conditions present.

c. Steam Thawing. - It is recommended that steam thawing experiments be carried out in 1956 in accordance with the plans originally drafted for 1955.

d. Study of Natural Thawing in Excavated Areas. - It is recommended that examination be made of the permafrost materials which have been exposed to summer thaw in past seasons by borrow excavations, both in the TUTO area and in the Thule Air Force Base area. Evaluations should be made of the time required for newly thawed materials to become sufficiently dry for use as fill, of pit drainage requirements, and of the rate of thaw penetration with depth in newly exposed permafrost.

16. <u>WORK OUTPUT STUDIES</u>. - An important part of the development of methods and techniques for the construction of roads in the TUTO area is the analysis of equipment and man power needs for a particular job. In 1955 a careful record was kept of equipment performance, time requirements, man power, etc. Such records should be repeated for all construction of this nature in 1956.

APPENDIX D
ESTIMATED COSTS FOR PROPOSED 1956-1957 PROJECT I PROGRAM

Notes:

(1) Salaries based on Civil Rates including 17% for leave fund.

(2) The number of personnel in the Field Staff has been planned to be sufficient to undertake a volume of work approximately equal to that completed in the 1955 program. If the entire proposed program for 1956-1957 were undertaken, including core boring, steam-thaw experiments, melt water volume studies, borrow methods studies, etc., two additional members should be added to Field Staff.

1 - GS-7 (Engineering Aide)
1 - GS-5 (Engineering Aide)

The following costs should be added to 01 Funds

1956 F.Y. $1,825
1957 F.Y. 4,560

The following costs should be added to 99 Funds

1956 F.Y. $ 560
1957 F.Y. 1,050

(3) No allowance has been made for spare parts for repair and maintenance of equipment. Approximately $25,000 might be required for this item.

(4) A drill rig with 3 men for 4 weeks would cost approximately $5,000 if no new equipment were purchased.

(5) Alternate 1 represents estimated cost without amounts involved in items (2), (3) and (4) above. Alternate 2 represents total estimated costs including above items.

Summary - Alternate 1

1956 Fiscal Year

01 Funds -

Preparation Period	5,820			
Preliminary Field Trip	973			
Field Period	8,055			
10% Contingency	1,485			
			16,350	
99 Funds -			10,000	
		Total	26,350	

1957 Fiscal Year

01 Funds -

Field Period	22,460			
Report Period	11,603			
10% Contingency	1,160			
			35,223	
99 Funds -			6,120	
		Total	41,343	
		say		41,350
		Grand Total		$67,700

Summary of Complete Costs for Entire Proposed Program

Alternate 2

1956 Fiscal Year

01 Funds	18,450	
99 Funds	11,620	
Spare parts, etc.	5,000	
		35,070

1957 Fiscal Year

01 Funds	42,500	
99 Funds	7,890	
Spare parts, etc.	20,000	
Drill Rig	5,000	
		75,390
	Total	$110,460

01 Funds - Fiscal Year 1956

Preparation Period

1 - GS-11 (Project Supervisor)	16 wks @ 305/2 wks	=	2,440	
1 - GS-9 (Assistant)	8 wks @ 251/2 wks	=	1,004	
1 - GS-5 (Assistant)	4 wks @ 170/2 wks	=	340	
1 - GS-3 (Draftsman)	4 wks @ 147/2 wks	=	294	
1 - GS-14 (Administrative Super.)	2 wks @ 487/2 wks	=	487	
1 - GS-13 (Administrative Super.)	2 wks @ 425/2 wks	=	425	
			4,990	
	10% Overtime		500	
			5,490	
	6% Division Overhead		330	
	Total			$ 5,820

Preliminary Field Trip 1 - 15 May

1 - GS-11, 2 wks @ 305/2 wks	=	305	
1 - GS-9, 2 wks @ 251/2 wks	=	251	
Overtime 92 hrs @ 3.93/hr	=	362	
		918	
6% Division Overhead		55	
Total			$ 973

Field Period

1 - GS-12 (Project Engineer)	4 wks @ 350/2 wks	=	700	
1 - GS-11 (Ass't. Proj. Eng.)	4 wks @ 305/2 wks	=	610	
1 - GS-11 (Construc. Super.)	4 wks @ 305/2 wks	=	610	
1 - GS-7 (Test Technician)	4 wks @ 209/2 wks	=	418	
1 - GS-5 (Surveyor)	4 wks @ 170/2 wks	=	340	
1 - GS-5 (Surveyor)	4 wks @ 170/2 wks	=	340	
1 - GS-5 (Instrument man)	4 wks @ 170/2 wks	=	340	
			3,358	

Overtime	444 hrs @ 3.93/hr	=	1,745		
	148 hrs @ 3.27/hr	=	484		
	444 hrs @ 2.64/hr	=	1,172		
				3,401	
25% Overseas Differential				840	
	Total Field			7,599	
	6% Division Overhead			456	
	Total				$ 8,055

Total	=	14,848
10% Contingency	=	1,485
Total 1956 Fiscal Year 01 Costs	=	$16,333

99 Funds - Fiscal Year 1956

Travel (Preparation Period)		300	
Per Diem (Preparation Period)		150	
Travel (to Field)		1,000	
Per Diem (in Field)			
2 men 14 days	84		
8 men 30 days	1,440		
		1,524	
Procurement:			
Test Equipment			
Thermocouples		800	
Radiation Measurements		2,000	
Miscellaneous		1,000	
Culverts		1,000	
Timber, lumber, etc.		1,000	
Miscellaneous (Camera film, etc.)		200	
Shipping Costs		200	
			9,174
10% Contingency			917
		Total	10,091

01 Funds - Fiscal Year 1957

Field Period

1 - GS-12 (Project Engineer)	10 wks @ 350/2 wks	= 1,750		
1 - GS-11 (Ass't. Proj. Eng.)	10 wks @ 305/2 wks	= 1,525		
1 - GS-11 (Construc. Super.)	10 wks @ 305/2 wks	= 1,525		
1 - GS-7 (Test Technician)	10 wks @ 209/2 wks	= 1,045		
1 - GS-5 (Surveyor)	10 wks @ 170/2 wks	= 850		
1 - GS-5 (Surveyor)	10 wks @ 170/2 wks	= 850		
1 - GS-5 (Surveyor)	10 wks @ 170/2 wks	= 850		
			8,395	
Overtime 1110 hrs @ 3.93/hr		= 4,362		
370 hrs @ 3.27/hr		= 1,210		
1110 hrs @ 2.64/hr		= 2,930		
			8,502	
25% Overseas Differential on 8,395		=	2,099	
1 - GS-14 (Consult. Super.)	2 wks @ 487/2 wks	= 487		
1 - GS-13 (Consult. Super.)	2 wks @ 425/2 wks	= 425		
Overtime for above - 148 hrs @ 3.93		= 582		
Consultant 2 weeks @ $50/day		= 700		
			2,194	
			21,190	
6% Division Overhead			1,270	
				$22,460

Report Period

1 - GS-11 (Supervisor)	18 wks @ 305/2 wks	= 2,745		
1 - GS-9 (Assistant)	18 wks @ 251/2 wks	= 2,259		
2 - GS-5 (Computers)	18 wks @ 170/2 wks	= 1,530		
1 - GS-3 (Draftsman)	18 wks @ 147/2 wks	= 1,323		
1 - GS-14 (Admin. Super.)	3 wks @ 487/2 wks	= 730		
1 - GS-13 (Admin. Super.)	3 wks @ 425/2 wks	= 637		
		9,224		
10% Overtime		922		
Reproduction of Report		800		
			10,946	
6% Division Overhead			657	
				$11,603
Total			=	34,063
10% Contingency			=	1,160
Total 1957 F.Y., 01 Costs			=	$35,223

99 Funds - Fiscal Year 1957

Travel (from Field)	800	
Per Diem (in Field)		
8 men 68 days @ \$6/day	3,264	
Travel (Report Period)	200	
Per Diem (Report Period)	100	
Shipping Costs	200	
Laboratory Tests	1,000	
		5,564
10% Contingency		556
Total		\$6,120